cost; and (d) list building materials and processes that produce offgases that are difficult to remove or control in structures.

2. Case studies of "problem buildings." NIOSH (National Institute of Occupational Safety and Health) and CDC (Center for Disease Control) maintain files of problem building investigations which they conduct. These health hazard evaluation records can be analyzed and compared with key building design variables to obtain profiles of design characteristics associated with problem buildings. This information can be used to develop more indepth studies utilizing site visits; interviews with designers, occupants, and building operators; and, possibly, measurements of key variables related to implicated pollutants. Further research can be identified relating to the contributions of the various contributors to the identified problems.

3. Potential impacts of current design and construction trends. Historical and prospective studies can be conducted through interviews with key decision-makers to determine probable short and intermediate term building design trends. These trends can be analyzed by comparison with existing buildings which are characterized and scaled with respect to indoor pollution levels. Further research needs and recommended design practices can be identified.

4. Problem building assessment. Many new buildings pose problems during initial occupancy periods. Techniques used in air hygiene, acoustical control, and epidemiology can be adapted for application by building designers and operators. Interviews, case studies, and other methods can be applied. Remedial actions can be studied to determine relative cost and effectiveness, based on case studies in lead paint and asbestos contamination abatement.

III A 2 Research Issue: Evaluation of the Health Effects of Building Materials

Some building construction materials have been found to have both short and long term adverse effects on the health of people who occupy the buildings. A methodology is needed to evaluate the potential environmental effects resulting from the use of a range of building materials. The results can then be used to develop design guidelines which will minimize the harmful effects of hazardous materials.

Research Topic

1. Develop a matrix that lists materials used in the construction of buildings and evaluate these materials in terms of current frequency of use and importance, possible substitutes, and potential for having an adverse effect on the health of occupants. This matrix can then be used to identify commonly occurring hazards and their potential effects relative to the possibility of substitutions, materials development needs, and methodology for evaluating new materials. In addition, further materials research priorities can be established based on the conceptual structures above, using technology assessment and risk methods. This assumes the development of an environmental toxicity modeling method, as well as specific criteria and measurement for particular materials.

III A 3 Research Issue: Impacts of Automated Office Equipment on the Health and Safety of Office Workers

We are entering an era of office automation, -- the introduction of sophisticated office equipment, such as video display terminals. Yet, we know little about the architectural implications, especially the potential health effects on workers.

Research Topic

1. We need to identify and describe trends in the installation and use of automated office equipment in interior work environments. Research should address the impact of the equipment on the physiological and psychological well-being of workers. We need to investigate the appropriate density of spatial arrangements, acoustical control, thermal comfort, air quality, color, lighting levels and type of glare, ergonomics and other human factors. This research effort will have direct impact on the quality and health and safety considerations in future work environments.

III A 4 Research Issue: Radon-222 Pollution

Within building structures, concentrations of radon-222, a daughter radionuclide of radium-226, tend to be substantially greater than outdoors. Radium is a naturally occurring and widely dispersed element and is found in soils and building aggregates such as sand, gravel, granite, et cetera. Energy conservation measures which retard air exchange result in elevated radon concentrations. Passive solar and super insulation applications are believed to increase the radiological exposure of occupants substantially. Two recent studies and models on the consequences of indoor radon exposure conclude that energy conservation measures may contribute 20,000 additional cancer deaths each year.

Research Topic

1. More extensive field data is needed on radon exposure in different buildings under different kinds of use in different areas under different atmospheric conditions. There is a need to determine if the problem can be reduced by simple ventilation of foundations and to determine the

best filters to entrap radon. In addition, materials should be tested for radium content before fabrication, in order to screen the most obvious culprits.

III B HUMAN SECURITY AND SAFETY: ACCIDENT AND DISASTER

A fundamental responsibility of building design is to provide for the physical safety of building occupants. Safety issues in design include protection from catastrophic building failure in natural and man-made disasters, limitation of the adverse effects of phenomena such as fire and pollution, and avoidance of conditions which contribute to accident occurance or anti-social behavior.

The public responsibility for health, safety and welfare provides the basis for public regulation of building design. The standards of acceptable design practice are, to large measure, set forth in publicly enforced codes and standards. The codifiction of standards of design to insure an acceptable level of public safety has led to a complex, costly, and often ineffective body of law.

It is now necessary to reevaluate the empirical basis of this body of regulation to determine scientifically if enforced provisions actually accomplish their stated objectives. It is necessary to collect and analyze actuarial data to evaluate the effectiveness and efficiency of the building regulatory system.

In many areas of building safety, major changes in technology and building use have occurred which require reevaluation of regulatory and design premises. Conflicts have arisen between competing objectives in building regulation. Increased safety is now at odds with cost control, energy conservation and efficiency of use. Methods must be developed to optimize design over the full range of building objectives including occupant safety.

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The following issues are included in this section:

1. **Procedures for Analyzing the Architectural Aspects of Total Building Failures**
2. **Degrees of Risk Associated with the Use of Properly Designed Building Elements**
3. **Security, Safety, and Energy Conservation**
4. **Safety and Disaster**
5. **Identification and Control of Coincident Hazards in Buildings**
6. **Urban Design and Seismic Safety**
7. **Codes and Standards**

III B 1 Research Issue: Procedures for Analyzing the Architectural Aspects of Total Building Failures

While recent building tragedies have been analyzed by fire protection engineers and behavioral scientists, virtually none of the "architectural" or spatial aspects have received serious scrutiny. Although buildings have failed "as a whole," the major findings produced by numerous technical investigations pertain only to the performance of components and subsystems. Despite the thoroughness and competence with which investigators from the NFPA, NBS, and other technical groups examine the remains and isolate component or subsystem violations, very little information bearing on the spatial aspects of buildings is ever produced. Even the trampling death of eleven teenagers at a rock concert in 1979 was treated solely as a crowd control problem by local and federal investigators. In an era when architects delight in experimenting with atriums, laryrinths, skywalks, and stairs to nowhere, it seems imperative that more systematic information be generated concerning the performance of these spatial innovations under failure conditions.

Research Topics

1. Reexamine and classify the architectural factors involved in the most critical building failures during the past decade, using existing records; characterize the processes which contributed to failure.

2. Develop protocols for preserving and examining the architectural evidence associated with major building failures. In addition, criteria should be developed for identifying failure incidents worthy of more intensive study or extensive reconstruction and simulation of the failure sequence.

3. Develop methods for attributing aspects of building failures to architectural, as opposed to engineering or behavioral, factors. This would probably involve extensive data collection and analysis, together with full-scale physical and computer simulations.

4. Develop a conceptual definition of "failure"; define criteria for failure. Define "architectural" as opposed to engineering or behavioral factors. Develop standardized procedures for analysis.

5. Develop the concept of "building diagnostics", including instrumentation for measurement and evaluation of parameters associated with building performance and failure.

III B 2 Research Issue: Degrees of Risk Associated with the Use of Properly Designed Building Elements

Building-related accidents involving individual occupants represent one of the leading causes of death and injury in the United States. They also represent an increasing source of liability claims against architects and building owners or managers. The primary elements involved are stairs, bathtubs and showers, nonglass doors, glass doors and windows, and slippery floors. Although extensive research during the past decade has revealed a number of architectural factors associated with such accidents, there is currently no data to indicate the expected frequency or severity of incidents associated with properly designed, installed, and maintained stairs, doors, or other high-risk building elements. Without such baseline data, it is almost impossible to determine whether a given level of performance falls within the range expected for a proper installation or if it might indicate the existence of a design problem or an abnormal pattern of use. Until some appropriate level of acceptable risk is established, a genuinely hazardous condition is quite difficult to define.

Research Topics

1. Epidemiologies of building accidents from NIESS emergency room data. Generate a typology of accident types, location, causes. Results would be used to indicate future research directions on a prioritized list.

2. Identify the frequency and severity of accidents involving properly installed building elements such as stairs, doors, and bathtubs or showers. This will probably involve new statistical treatments of existing accident and building census data, as well as the collection of new data under controlled conditions.

3. Establish post-incident accident investigation formats that are more sensitive to the architectural aspects of such incidents than the product and operationally-oriented instruments currently used by CPSC and OSHA.

4. From an accident etiology (prioritized list), examine the accident mechanisms through simulation techniques and case studies of accidents.

Develop and evaluate counter-measures.

5. Investigate social and economic constraints on design for public safety; make explicit the trade-off of safety-economy and safety-convenience for consumer products in buildings. Develop a general model of building product use which includes aspects of utility and risk for relevant populations.

III B 3 Research Issue: Security, Safety, and Energy Conservation

As concerns for the costs of energy have developed, the basic designs of buildings have begun to change. Some of the changes, such as the inclusion of atriums and greenhouses, could compromise the safety and security of the occupants and their property. Evaluations of new and additional criteria are needed which will assure the safety and security of occupants and their property in energy efficient buildings. This issue relates to the larger issue of design for multiple objectives, and optimization over a wide range of variables.

Research Topics

1. Thermal insulation and fire safety. The thermal resistance imposed by insulation in building walls, ceilings, and floors could have significant influence on the rate of rise of temperature in an occupied space during a fire emergency. Furthermore, the insulation material may outgas toxic or lethal products at these elevated temperatures. Systematic study should be conducted to estimate the extent of this problem in terms of material characteristics, and in forms of latency periods to allow escape. The results of this investigation are needed for specifications of "safe" materials and for possible alterations of fire escape procedures.

2. New uses of glass and safety. Glass and plastic glazings are finding increased uses in passive and active solar energy systems. The location of these products for energy efficiency may not always be compatible with safety and security criteria. Surveys should be conducted to determine the more frequently occurring violations to safety and security criteria. The cases could be analyzed to determine what alternatives could have been chosen to provide for energy efficiency without compromising safety or security. The results of this study should aid designers and provide information to code-writing bodies.

III B 4 Research Issue: Safety and Disaster

We need to know more about the relationship between buildings and a full range of natural and man-induced disasters: earthquake, flood, hurricane, and fire. We need to know more about the relationship between design and actual use, and between those elements and the occurance of injury and death in disaster situations.

Research Topics

1. We must study occupant behavior in disasters with a view to finding key issues that determine probable behavior. There is a need to focus on what people do, rather than what they say they will do. When does the building help, by protecting, or act as a threat, by creating otherwise nonexistent dangers?

2. The detailed investigation of building behavior in disasters with a view to determining the extent to which life endangering hazards are building specific: leading to managerial and operational measures that improve occupant safety.

3. Evacuation of persons in incidents of building fire. Persons incur death

and injury due to fire within buildings even though numerous standards and codes regulate the design aspects of fire safety, including circulation and egress. The relationship between codes, safety systems, circulation, egress, and fire-related death and injury should be investigated via case studies of such incidents. Secondly, simulate alternative responses of certain critical groups: children, blind, elderly, and handicapped users. Findings would impact on design concepts, standards, and codes.

III B 5 Research Issue: Identification and Control of Coincident Hazards in Buildings

Occasionally the physical juxtaposition of two or more nonhazardous building elements can create a serious secondary hazard. A common example would be a clerestory positioned such that the direct rays of the sun can momentarily blind a person approaching a physical obstable or a stairway at certain times of the day or year. In another example, several serious accidents have been associated with openings in walls that enclose a stairway, particularly where the openings suddenly reveal compelling views that draw the user's attention away from where he or she is going. In these cases, the hazard is not created by the stair, the clerestory, or the wall opening, but by the manner in which these elements are positioned relative to one another. Another type of coincident hazard occurs where two or more minor hazards interact to create a much more serious problem. A classic example occurred in 1980 when PVC gas from an exploding transformer combined with the fumes from burning wall coverings to produce Agent Orange in an office building. Given the frequency with which new materials and new spatial configurations are introduced to the built environment, and given that the technical information behind these innovations is fragmented across numerous disciplines, it would appear that a major interdisciplinary research effort is needed to avoid numerious minor incidents and perhaps several major catastrophes in the future.

Research Topics

1. Document and classify previous incidents involving coincident hazards, using existing data. Such studies are needed to determine the extent of the problem and to begin to conceptualize it in researchable terms.

2. Develop procedures for identifying coincident hazards in the field and for anticipating them during the design process. One starting point for such research might be an analysis of the conflicts between existing standards and regulations for fire protection, consumer safety, building security, and energy conservation.

III B 6 Research Issue: Urban Design and Seismic Safety

Advances have been make in the performance of buildings in seismic areas, but little or no research has been carried out in the relationships of urban planning and design to earthquake hazards mitigation programs. Urban designers have a holistic approach to the planning and design of metropolitan areas, but many do not take into account planning efforts to mitigate earthquake disasters and other natural hazards.

Research Topics

1. Relationships of urban design to earthquake risk assessments and risk analysis should be subjected to research activity. Land use planning, transportation systems, communication linkages, critical use facilities, and other components of the urban environment should be investigated for their role in hazards mitigation.

2. Develop protection procedures for fire expansion following earthquake, including defense for high rise buildings in cities. Investigate zoning systems for fire protection areas. Evaluate evacuation strategies.

III B 7 Research Issue: Codes and Standards

Many of the codes, standards, and regulations that specify or dictate architectural solutions and are intended to protect human security and safety are based on little more than untested common sense or conventional wisdom. These regulations may not be contributing to security, safety or human welfare at all and may be partially responsible for substantial additions to the cost of producing and maintaining environments.

Research Topic

1. Carry out historical analyses of the origins of specific elements of building regulation. What were they intended to accomplish; what was the empirical knowledge base for regulation decisions? Have conditions changed? Which regulations need retesting and reformulation from a contemporary, scientific viewpoint.

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IV. CONSERVATION OF RESOURCES

A. Building Economics

B. Building Systems

C. Reuse

IV A CONSERVATION OF RESOURCES: BUILDING ECONOMICS

Introduction

The building industry is a major component of our nation's economy by any measure. It tends to be viewed in macro-economic terms, -- responding to major movements in the economy. Likewise, each building project responds to a regionalized or localized set of economic and financial factors. Yet, we know very little about the micro-economics of buildings, -- the economic behavior of persons constructing and operating buildings. We know even less about the economic consequences of our design decisions. At this point in history, the conservation of resources, the rational use of land, labor, and capital, will be imperative for the building sector.

This first set of research issues deals with a sample of fundamental economic questions in architecture: economic performance and effectiveness, resource use, and economic analysis methods. The issues are as follows:

1. **Economic Performance of Buildings**
2. **Economic Effectiveness of Predesign Programming**
3. **Construction Cost Estimating and Control**
4. **Building Economics, Design, and Post-Construction Management**
5. **Productivity Measurement Methodology**
6. **Energy Use in the Construction Industry**
7. **Urban Form and Energy Consumption**
8. **Design Decisions and Tax Policy**

IV A 1 Research Issue: Economic Performance of Buildings

Building performance has many dimensions: construction cost, aesthetic value, user satisfaction, functional adequacy, and so forth. Recently, the explicit consideration of economic performance has become integrated into the design process. A number of economic analysis techniques have emerged, with major impacts on our ability to predict the performance of various building design alternatives. For example, life cycle costing and value engineering have created opportunities for increased productivity, by affecting the way we view productivity and performance, and thus, the way we view building design. For example, when the resources of land, labor, and capital are related to final output over time, the importance of construction cost diminishes relative to labor. Thus, the design for efficient labor becomes paramount in many building types (e.g., hospitals).

Although the use of economic analysis techniques in the design process is spreading rapidly, we know very little about the effectivenss and potential impacts of such analysis.

Research Topics

1. Development and quantification of measures of economic performance in buildings, including case studies to estimate economic performance parameters by building type and location.

2. Identification and evaluation of the variations of economic analysis techniques used in the design process, including controlled experiments comparing model values with as-built values, and the development of improved methodologies.

3. Development of design decision models that integrate economic analysis techniques with contemporary building evaluation methodology for purposes of design proposal evaluation and rehabilitation timing

decisions.

4. Analysis of the effects and potential effects of life cycle costing, value engineering, and other economic analysis techniques on building design decisions and as-built performance (e.g., on building configuration, material selection, mechanical systems), via case studies across building types and locations.

IV A 2 Research Issue: Economic Effectiveness of Predesign Programming

The emerging area of predesign architectural programming promises opportunities for more responsive building design solutions by bringing relevant information on all expanded sets of issues to the design process. Although the techniques of programming are well-integrated into architectural practice, little is known about the economic effectiveness of programming efforts relative to the success of the final building product.

Research Topic

1. Evaluation of the effectiveness of predesign programming efforts in terms of the impact on building performance (construction cost, user/owner satisfaction, productivity, etc.) via case studies of various programming levels across a variety of building situations. The emphasis would be on identifying situations where programming efforts could have major positive economic impacts, and on the systematic evaluation of various programming methods.

IV A 3 Research Issue: Construction Cost Estimating and Control

Uncertainty in construction costs plays a major role in the structure and processes of the building industry. Various techniques to estimate costs before construction, and to control costs during construction, permeates decision processes from predesign to final occupancy. Any marginal improvement in cost estimating and control would have a major impact on productivity.

Research Topic

1. Identification and evaluation of various cost prediction and control methods via case studies of actual design and construction situations, including the development of improved methodology.

IV A 4 Research Issue: Building Economics, Design, and Post Construction Management

There is a fundamental relationship between the design of a building and the system of managing the operation of the building. For example, design details and materials imply a system of use and maintenance. Each combination of materials and use yields economic costs and benefits over time. Yet, decisions about design detail and material selection are not well-integrated with facility management decisions on the typical project. It is not unusual to find detail-material combinations being used in an unintended way after a building is occupied.

Research Topics

1. Identify and quantify the economic consequences over time of a variety

of typical or critical design detail-materials combinations in a wide range of use situations.

2. Develop an empirically-based model of the relationship between building design, subsystems, details, materials, occupancy, and operational management systems.

IV A 5 Research Issue: Productivity Measurement Methodology

How does one measure productivity in the built environment? What aspects of the built environment affect productivity, and how? We need to develop acceptable and reliable measures of productivity, and to describe the basic relationships between attributes of the built environment and productivity. Consideration of final product attributes needs to become integrated into the architectural design process. Yet, currently there is little in productivity theory or method that is useful to the building designer.

Research Topic

1. Measures of productivity and built environment variables that influence productivity. There needs to be some basic conceptual structuring of the concepts of productivity relative to buildings, followed by the development of appropriate criteria and methods of measurement. Such methodology needs to be developed and tested over a wide range of building types and economic endeavors.

IV A 6 Research Issue: Energy Use in the Construction Industry

Despite the fact that the construction industry represents a significant part of our gross national product, and is one of our largest industries by any measure, we actually know very little about the economic functioning of this aggregated, regionalized industry. Particularly, we know very little about the use of energy in the industry, -- from the production and transportation of building materials to the construction and maintenance of buildings. A large, systematic view of the industry could yield useful insights, -- affecting design as well as public policy.

Research Topic

1. Basic conceptual and descriptive structuring of the building industry, with economic modeling techniqes, to provide an understanding of energy consumption at various stages of construction industry operation.

IV A 7 Research Issue: Urban Form and Energy Consumption

Various patterns of urban development (location, density, etc.) produce various patterns of energy use. Understanding these relationships at an urban scale is extremely important in terms of resource conservation for future urban development.

Research Topic

1. Quantitative assessment and theory building in the area of urban development form and total resource use, using field study observations and survey research to characterize and measure various urban forms and energy use patterns.

IV A 8 Research Issue: Design Decisions and Tax Policy

Building owners increasingly determine major building characteristics as a result of tax policy. The real impact of tax policy on building design with respect to energy conservation, building performance for its functional objectives, environmental quality (and its impacts on occupant behavior and health), and other owner and designer objectives is poorly understood. Case studies, dynamic models, interviews, and other methods can be applied to develop a better understanding of such incentives as the Calfornia and federal solar tax credits, building depreciation allowances, and other factors.

Research Topics

1. Comparison of California and federal solar tax credits. California has the largest tax incentives for the use of solar energy in the United States. A comparison with national experience and with selected regions or subregions based on climatic similarities, lifestyle similarities, and building design similarities and differences can result in an increased understanding of the impact of tax incentives.

2. Building depreciation allowances. Component depreciation, accelerated depreciation, and other tax rules and regulations can be analyzed in a dynamic model using actual case studies of recently designed commercial and institutional structures.

3. Public and private building design. Tax structures can be compared with interest rates, corporate goals and objectives, and other differences between public and private entities in building types including office buildings, employee housing, publicly and privately subsidized housing (many universities have now constructed housing to assist new faculty), warehouses, auditoria, and others. These comparisons can reveal through sensitivity analysis the importance of various factors in design decision-making and assist in adjusting priorities to more closely match corporate

goals, as well as inform policy-makers of the impact of tax and fiscal policy and regulation.

IV B CONSERVATION OF RESOURCES: BUILDING SYSTEMS

Introduction

This section of conservation of resources addresses the fact that buildings are major users of scarce resources, especially energy. During the 1970s we faced a significant increase in concern over energy conservation in buildings, resulting from the nation's first energy shortfall and the subsequent dramatic rise in energy prices. It is likely that this concern will continue and intensify, and thus it is important that we increase research in this area.

Generally, the components of energy use in buildings are terms "building systems." Research needs include the exploration of the relationship among building system attributes and energy use, the effects of systems on users, and the roles of users of the systems.

1. **Impacts of Resource Conservation on the Interior and Exterior Environment of Buildings**

2. **Role of Operators and Occupants**

3. **Occupant Control of Environmental Conditions**

4. **Building Form and Energy Use**

5. **Energy and Environmental Modeling for Building Performance**

6. **Renewable Resource Base for Building and Community**

7. **Prediction of Infiltration Rates**

8. **Natural Ventilation**

9. **Building Envelopes**

10. Solar Energy Utilization

IV B 1 Research Issue: The Impacts of Resource Conservation on the Interior and Exterior Environment of Buildings

The interaction of the various aspects of interior and exterior building design and the potential tradeoffs in construction cost, energy conservation, and occupant satisfaction have stimulated research of interest to architects, landscape architects, architectural engineers, and social scientists. To date, this research has, however, focused more on the exploration of building failure than on critical relationships among operating factors. A number of thse factors should be systematically investigated.

Research Topics

1. Interrelationships between daylighting, energy consumption and environmental quality. Daylighting may contribute to more effective use of energy resources if the thermal and lighting energy requirements are quantified with consideration for losses in the use of electricity. Furthermore, the quality of light in occupied space may be enhanced through improved control strategies for daylighting. Analytical models for predicting lighting quality and energy resource requirements should be developed and validated with experimental data obtained through field studies. The results of this investigation should influence design decisions regarding window size and location, location of buildings on sites, relationship to adjacent buildings, and landscaping. They may also have a significant influence on building codes.

2. Interrelationships between natural ventilation, energy consumption and environmental quality. Operable windows serve as a primary means of ventilation in most small buildings. However, they may also require

additional energy consumption due to the increased thermal loads they impose on occupied spaces. Research should focus on the development of control spaces which enhance the ventilation effects through windows, but which minimize energy consumption. Analytical methods should be developed to allow prediction of performance. Methods could be validated through field studies. Factors to be considered include: wind speed and direction, turbulence intensity and frequency, quality of outdoor air, and indoor environmental requirements. The results of the investigation should impact both the architectural and mechanical design of systems which comply with this strategy.

3. The complex interrelationships associated with windows. Rising utility costs have stimulated renewed interest in building fenestrations. Trade-offs in design must be examined for relative impacts on electrical costs and heating costs, aesthetic quality, the interaction of buildings with the environment, and social and behavioral impacts on building occupants. Investigations may include benefit/cost analysis, life cycle costing and/or case study analysis. Findings would impact building design, planning standards, and contribute to ecological, environmental and economic theories relative to design for energy efficiency.

IV B 2 **Research Issue: Role of Operators and Occupants**

The role of human occupants and operators in building energy consumption. Every analytical technique for predicting building energy consumption is limited by simplistic assumptions about the role of human behavior in affecting that consumption. This behavior has been shown to account for as much as a 50% variability in energy consumption between identical buildings. It introduces greater uncertainty into our predictive methods, and it also presents a great opportunity to conserve energy resources if properly managed. We need to understand these relationships.

Research Topics

1. Measuring the variations in building energy consumption due to the behavior of both occupants and building operators. Several different building types would be studied. Measurements of actual consumption under different building use conditions would be compared to predictions by analytical techniques. The resulting data would provide a basis for more detailed studies into specific aspects of behavior.

2. Evaluating the success of energy conservation measures which consist of modifying occupant or building operator behavior. Case studies of the successes and failures in implementing these changes and in saving energy would inform engineers' and architects' efforts to design buildings, systems, and operating strategies that conserve energy.

IV B 3 Research Issue: Occupant Control of Indoor Enviromental Conditions

Is it usually assumed that optimizing building operation requires decreased or prohibited occupant control of such systems as lighting, ventilation, heating, and cooling. In fact, however, many energy conservation efforts have failed to achieve the expected reductions in energy use due to occupant interaction with building systems. We need more information on occupant behavior and interaction with building controls. We also need to explore new systems which can allow some (or even maximize) occupant control within defined limits, and even provide immediate feedback to the user as to the effectiveness of his action. We might even devise systems where occupant controlled tradeoffs can be interactive and limited within designer-specified parameters. New systems of control and increased understanding of occupant or user needs and behavior is required to achieve improved building performance.

Research Topics

1. Energy conservation retrofits and occupant behavior in relation to actual energy performance. Several well-documented retrofit programs such as Twin Rivers (Princeton University) and Residential Conservation Service (California Energy Commission) in residential programs and the World Trade Center Lighting Project (Lawrence Berkeley Laboratory) in commercial programs provide a data base for case studies, comparative analysis, interviews with designers and user-occupants, and investigation of actual versus expected savings. New hardware such as photocells, microprocessors, infrared viewers, and others can be used to develop new experimental and building design. These innovations can be tested in on-going laboratory settings, through case studies of field trials, and by simulations in both laboratory and field situations. Actual energy consumption measurements can indicate the effectiveness of these innovations.

2. The use of microprocessors creates the potential for developing feedback systems to provide occupants with information on the impact of their actions. This feedback can include prosections of actual environmental conditions, energy use, cost or other factors. Monitoring of results can inform us on the effectiveness of feedback itself to achieve results such as controlling costs and energy use of environmental conditions.

IV B 4 Research Issue: Building Form and Energy Use

Forms of buildings and building groups constitute a set of complex factors that effect the consumption of energy in buildings and building infrastructure. This is a relatively new area of investigation of interest to architects, engineers, developers, et cetera. Although useful information is being produced daily, it is fair to say that the vast majority of needed research has not yet begun. Traditionally, buildings and building complexes have been designed with little regard to the energy effects of the building form and site environment (both natural and man-made; e.g., adjacent building, solar access, micro-climate, existing infrastructure). Yet, these factors are related directly to energy consumption.

Research Topic

1. Development of a set of physical and symbolic models for testing various building and complex forms in relation to energy consumption, including validation of models through field studies. Eventual development of building form simulations, both physical and symbolic.

IV B 5 Research Issue: Energy and Environmental Modeling for Building Performance

There exists a need for flexible and reliable computer models that are calibrated against actual building performance.

Research Topics

1. Energy consumption models for existing (as well as for new) buildings are needed: first, methodologically, to test empirically, and calibrate the models with historical data; second, predictively, to provide guidance for energy system development where existing buildings are modified. These models would be developed from rational algorithms.
2. Development of site-specific methods for predicting indoor performance. Models are needed which can be used to predict environmental quality within occupied facilities. As a minimum, these models should include estimates of environmental exposure to thermal factors, gaseous and particulate contaminants, and UV visible and IR radiation. These models

would be developed from rational algorithms and would be validated against actual building performance. The models would be useful in cost-benefit analyses of alternative control strategies that might be considered in new or existing buildings.

3. Retrofit models. When oportunities for retrofitting buildings arise, special attention should be given to the performance of the original systems. This investigation would use modern techniques of performance simulation for analysis of these systems. The results will provide increased sensitivity toward historic, existing systems. They will also provide insight into procedures for adaptation of the principles used in the original designs when retrofitting the facility.

IV B 6 Research Issue: Renewable Resource Base for Building and Community Utility Systems

Development of the technical basis for the transfer of building and community utility systems to a renewable resource base. Each year increases our awareness of the need to transfer our buildings and communities from an expendable to a renewable resource base. The most obvious pressures have come from the recent disruptions of traditional fuel supplies, but the issue is more than alternate energy supplies. The depletion of resources is currently balanced by the production of waste; garbage, pollution, waste heat, waste of space and resources in the disposal process, and the waste which is a result of the loss of resources for other uses. In recent generations, traditional processes of reuse and renewal have been supplemented by new, more linear, processes with increasing quantities of useless, unhealthy and dangerous waste. Contemporary buildings and communities take their form from these processes. In the coming years, healthy, productive and economic communities will depend on the return, at a new scale, to integrated communities using renewable resources.

Research Topic

1. Exploratory and conceptual structuring studies of the effect of alternative approaches to energy, water, waste, transportation, communication, food production, et cetera on human settlement patterns; dwellings, communities, and cities. The development of new technologies for communities, — tools and techniques which will transfer the focus from individual buildings to groups and communities.

IV B 7 Research Issue: Prediction of Infiltration Rates

In the recent quest for a better understanding of energy flows in buildings, significant advancements were made in the prediction of conductive gains and losses through the building exterior as well as in the area of solar gains. Air filtration can contribute 50% of the load. In some building types, the methods by which to predict the amount of infiltration are ineffective.

Research Topic

1. Develop research methods for predicting air infiltration. Develop general design principles, adequate for different levels of energy analysis. Prediction methods should be constructed around building types, construction types, climate (macro-micro), and particularly wind speeds.

IV B 8 Research Issue: Natural Ventilation

We cannot answer systematically the question of whether natural ventilation can provide a satisfactory interior environment in a given climate, in a particular building situation. In addition, we are only beginning to understand how to design naturally ventilated buildings effectively.

Research Topics

1. The systematic estimation of comfort requirements and pollution infiltration, taking into account different populations and levels of adaptation, across climates and building types.
2. Methods of climatic and particularly microclimatic prediction to allow designers to determine the ventilation potential directly surrounding a proposed building. The research should probably focus on numerical techniques in order to support development of computerized design tools for predicting local climate.
3. Building forms and details for effective ventilation of the interior. The research would be done by both testing a variety of physical models in a wind tunnel and developing numerical models of forced and thermal ventilation that may eventually be used in the design process. Designers would benefit at many levels, from catalogs of successful designs to complete design tools based on wind tunnel measurements and computer simulations.

IV B 9 Research Issue: Building Envelopes

The envelopes -- walls, floors, roofs -- of most buildings are essentially inert thermal barriers blowing the heat inward or outward, but not actively regulating indoor conditions. A more nearly ideal envelope would react to surrounding conditions, indoors and outdoors, to maintain desired conditions in the building. It would regulate temperature in a room at one level while the room is occupied, but sense when it is unoccupied and allow temperature to rise or fall, it would regulate air movement, it would turn light and other equipment on and off, thereby minimizing energy requirements. We need basic experimental studies on the attributes of active envelope systems.

Research Topic

1. An interdisciplinary team of professionals should be assembled to explore possible approaches to fast response active envelope systems. Possible approaches include radiant walls and ceilings, as well as means of controlling air circulation and temperatures simultaneously. Another aspect concerns materials to be employed for the radiant surfaces and the body of the envelope. These might include constant-temperature materials such as latent-heat storage materials, low-storage high-insulation materials, or combinations, and their regeneration as necessary (night-time, for example).

IV B 10 Research Issue: Solar Energy Utilization

Solar energy utilization has had an important impact on the building industry, especially the area of residential building design. Five major types of "passive" designs are now commonly used throughout the country. All five of these design concepts incorporate major changes in the location, size, and design of glazing areas. These changes vary from the extreme of the Trombe wall to the well-accepted repositioning of standard window and door units from the north to the south orientation. The addition of movable insulation to cover the glazing area during winter heat loss (or summer heat gain) is also now a commonly accepted practice. All these changes in window appearance and utilization have a significant impact on the use of interior space and energy consumption.

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Research Topic

1. Among the topics to be investigated are user behavior and user satisfaction as affected by changes caused in interior space design and utilization, and the use of different materials, furnishing and equipment. Survey research of a sample of households, mainly in the Northeast, is needed. Comparative measures of light, temperature, energy use would be made with a control group of households with similar demographic characteristics. General conclusions would be reached to improve both design and acceptability of glazed areas, and particular interior treatments of passive solar structures.

IV C CONSERVATION OF RESOURCES: BUILDING REUSE

Introduction

A large portion of capital invested by society resides in our existing building stock. Daily, millions of dollars flow into this medium. Wise use of resources (including capital) requires that we understand the long range consequences of investments in our built environment and the impact of our built environment on these investments. Yet, aside from business-oriented typologies for capital employment in buildings (e.g., discounted cash flow modeling), we do not have an adequate means for representation of this phenomenon. Without this means, the prediction and evaluation of capital employment is impossible. Understanding what such typologies are and how to predict and evaluate capital employment in buildings is the major research issue pertaining to reuse.

Another set of questions concerning existing building stock focuses on the growing trend of adaptive reuse, -- in terms of design process and technology. Results from this research will provide knowledge to the building owner, developer, and designer which will allow them to make more rational decisions about the potential reuse of buildings and related potential conservation of resources. Furthernore, such research is required to allow for the systematic establishment of future research on related but more specific technical topics, such as materials which prolong useful building life, physical processes for rehabilitation design methods which result in increased building life, and new institutional arrangements which increase the long term economic utility of buildings.

1. **Embodied Capital in Buildings**

2. **Functional Change and Building Performance**

3. **Preservation and Adaptive Reuse of Existing Buildings**

4. **Preservation Technology**

IV C 1 Research Issue: Embodied Capital in Buildings

A major resource is the previous capital investment in buildings. Buildings can be viewed as embodied capital. Efficient use of this resource include understanding the causes of obsolescence, which is the result of inefficient use of embodied capital. Techniques of reuse and of increasing the flexiblity of building sub-systems are means to increase the utilization of embodied capital. Maintenance also influences the use of embodied capital. Research is needed to understand the representation of embodied capital in buildings and how the above factors are used in the prediction of building obsolescence and timing of investment.

Research Topic

1. The survival of buildings appears to be a Markov Chain process. Probability of destruction of a structure appears greatest in the first 25 years of its existence. The process of accretion of the stock of buildings in a region appears to be one of continual addition of new structures and replacement of older ones, to a large extent those recently constructed. The building industry, in a sample region or regions, needs to be studied to determine rates of new construction, replacement and demolition, to understand how the total stock of structures is continualy modified. Economic and institutional factors that influence these various rates need to be investigated and understood.

IV C 2 Research Issue: Functional Change and Building Performance

Conflict between the permanence of buildings and the increasing rate of social or functional change. The fixed nature of building pre-determines spatial and other functional uses of the built environment and places society in a "straight jacket" of physical structures that may be at variance with future needs for buildings. We need to understand the relationships between cultural and economic diversity, and building form. How much change can society accommodate? Does the difference in the rate of change in buildings historically and culturally place a drag on societal develoment, or is it a beneficial moderating influence?

Research Topic

1. Investigation of the economic and social benefits or costs of multipurpose buildings, including the analysis of economic or cultural bases for making those buildings obsolete. Also, an examination of the relationships between providing flexibility in building use and the future cultural and economic worth of the building.

IV C 3 Research Issue: Preservation and Adaptive Reuse of Existing Buildings

A major portion of construction activity consists of maintenance, renovation, reconstruction and remodeling of existing buildings. While this is a major area of architectural concern, it has received little formal attention.

Research Topic

1. If the processes of maintenance, renovation and remodeling were better recognized and better understood as major elements of construction activity, possibly more conservation of existing structures would occur. Development of protocols for modifying existing buildings to meet new requirements need to be developed. Procedures for updating structural and mechanical systems need to be investigated and specified. New techniques, materials and equipment need to be developed to facilitate renovation and conservation of existing buildings.

IV C 4 Research Issue: Preservation Technology

A great emphasis on preserving old buildings has occurred for a variety of social, economic, and political reasons. This trend has advanced more quickly than the extant technologies to achieve these ends. The preservation of historic building is being hampered by the inadequate technology for repairing and maintaining historic materials.

Research Topic

1. Set up a collaborative venture with historians, buildings technologists and industrial chemists to explore some of the most serious problems that have emerged from case studies in cities of the United States and other countries. Develop a materials and structural research program to study the problems. Results would extend the life of historic structures, and reduce the costs of maintenance.

V. STRUCTURAL, MATERIAL, AND EQUIPMENT SYSTEMS

A. Systems

V STRUCTURAL, MATERIAL, AND EQUIPMENT SYSTEMS

Introduction

This section of the research agenda addresses a sample of issues and topics that focus on the characteristics and performance of building conponents. Section IV, Conservation of Resources, dealt explicitly with other relationships, such as the characteristics of materials and the interaction of those materials or systems with other important factors. Although each item presumably receives research attention in other fields and with product developers, this agenda attempts to demonstrate the need for research on the interaction of material and equipment systems with other factors, including whole building performance. We just don't know enough about the integration of structural, material, and equipment systems in terms of final product performance.

1. **New Material Characteristics**
2. **Long Term Behavior of Plastics and Composites**
3. **Pollutants and Building Materials**
4. **Water Infiltration in Buildings**
5. **Technology of Building Rehabilitation**
6. **Luminaire Performance and Human Performance**
7. **The Effects of Vibration Pollution of Human Performance**

V A 1 Research Issue: New Material Characteristics

New materials and system components are being added continually to the list of existing materials for building. The architect, engineer, contractor, official, and builder are frequently faced with the selection or rejection of the new item without adequate information to guide the decision. The material manufacturer and supplier do not always understand what the user needs to know and/or fail to provide adequate technical information. The result is often rejection or misapplication leading to failure. New materials information, independently evaluated, is needed for the industry.

Research Topic

1. An interdisciplinary team of experienced practitioners could be assembled to prepare a guide setting forth the types of information that should be made available to architects, engineers, building officials and contractors to enable them to make intelligent choices of new materials and components for building. A separate manual prepared by a team for each of the above might be warranted. These would act as guides to the manufacturer to make sure that important aspects are covered. Such an effort might eventually lead to something like the European Agreement systems of certifying new materials and components. This assumes, as well, fundamental research on the descriptive criteria, measurement standards, and pilot applications.

V A 2 Research Issue: Long Term Behavior of Plastics and Composites

Relatively new building materials, such as plastics and composites, are frequently not used, or adapted slowly, because of uncertainty about long-time performance in buildings. Short term and small scale laboratory tests do not predict necessarily how the materials and components will behave in practice. Information is needed regarding the actual behavior of these materials in use. Plastics, and composites based on plastics, although relatively new, have been in use long enough in a great diversity of buildings to provide sufficiently extensive information.

Research Topic

1. A systematic study of the actual histories of important plastics and plastics-based composites in actual use in a representative cross-section of buildings, to determine how they have performed under diverse conditions. Composition, fabrication, installation and maintenance should be reviewed to determine the factors that have led to success or failure. Although plastics and plastics-based composites are specifically mentioned, the same holds true of other new materials such as coatings, sealants, roofing, particle board, and others.

V A 3 Research Issue: Pollutants and Building Materials

Acid rain has been added to the other pollutants in the air over the years to provide an aggressive atmosphere that attacks building materials. The problem is not new, but is intensified, and solutions have not been found. There is concern and some evidence that acid rain not only attacks stone, metal elements, and mortar in brickwork, but that such rain running off eaves may be penetrating into the ground and attacking concrete foundations. Where soil is normally alkaline, it may become acidic, changing the kinds of vegetation that can be supported. If water supplies become acidic, the detrimental effects on piping and plumbing can become serious.

Research Topic

1. Two phases are suggested specifically for foundations: (1) laboratory simulation of acid rain penetrating soils of various kinds adjacent to concrete to study possible deleterious effects; and (2) field observations in areas of known highly acidic rain to determine actual acidity of soil adjacent to foundations, and effects on concrete block and monolithic walls. These suggestions are limited to this particular topic. The much larger problem of the effect of atmospheric pollutants on buildings should be addressed as well. For example, we need information to develop prescriptions for affected materials, new materials, and methods of construction.

V A 4 Research Issue: Water Infiltration of Buildings

Countless examples of water infiltration of buildings occur in practice, literature, and liability cases. However, little research has been accomplished in this area. Most buildings, particularly high-rise buildings and innovative designs, are susceptible to water infiltration, -- much to the consternation of building owners. Window components, wall assemblies, door systems and other building elements have not been subjected to relevant large scale testing in the architectural laboratory.

Research Topic

1. Laboratory testing of water infiltration in typical architectural systems, as well as case studies of building failures, are required to develop better design, construction methods and materials.

V A 5 Research Issue: Technology of Building Rehabilitation

The technology of building rehabilitation is based primarily on traditional knowledge, yet many new materials are being introduced to the field. Even traditional materials are being used in new environments. The results of this mismatched technology are frequently the increased deterioration of existing building materials and eventually, entire buildings.

Research Topics

1. Identification and measurement of the consequences of insulating masonry walls. It is feared that the addition of insulation to an existing masonry wall will increase its susceptibility to frost. Tests of consequences should be undertaken on various masonry walls in actual buildings. Each type of wall would be studied in both an uninsulated and insulated condition, to eliminate environmental and constructional factors. Thermocouples and moisture meters would be installed in each wall at its interface to allow continuous monitoring of thermal gradients both seasonally and daily. Infra-red measurements would also be useful.

2. Testing low pressure abrasive cleaning of existing exterior materials. The destructive action of high pressure sand blasting has been described often; low pressure techniques need to be tested. A variety of building stones and bricks could be cleaned with silica or alumina oxide using low pressure guns, and then inspected to detect changes in surface structure. Laboratory tests would be undertaken to compare surface area, porosity and permeability. Samples could also be subjected to salt penetration tests.

V A 6 Research Issue: Luminaire Performance and Human Performance

Emphasis has been placed traditionally on minimum illumination levels for various tasks and on design strategies for reducing glare. However, there is increasing evidence that the type of lamp (e.g. incandescent, florescent) and the color of one's suroundings may affect thermal comfort; susceptability to, as well as recovery from, illness; and ability to cope with stressors. Whereas some European countries have established minimum CRI's (Color Rendering Index) for luminaires to be used in various settings, there has been relatively little research on this important topic and on related issues in this country, except for that done by product manufacturers.

Research Topic

1. The effects of luminaires with differening CRI's on (a) recovery time from illness in hospitals, (b) absenteeism in the office, (c) level of social interaction in geriatric settings, (d) activity level of kindergarten children, using motion and time study techniques, unobtrusive measures, and other techniques of human factors and environmental psychology. Results would provide direction for establishing CRI standards for different settings and populations. Study of UV and IR radiation should be included as well.

V A 7 Research Issue: The Effects of Vibration Pollution on Human Performance

While there has been considerable research on the effects of low frequency vibration (below 20 Hz) on human performance and health in exotic environments (space and aircraft) and in product design (e.g. power tools, tractor design), there has been relatively little research on vibration in other aspects of the built environment. Since all body segments, organs, and tissues have resonant frequencies, it is possible that vibration may constitute a stressor in residential as well as work settings.

Research Topic

1. Vibration pollution in multi-story apartment buildings and condominiums. Analysis of the frequency, intensity, and duration of vibration as it relates to (a) proximity to vibration source, (b) time of day and season, (c) building materials and construction methods (e.g. STC ratings of materials), and (d) resonant frequencies of body segments, organs, and tissues. Results would provide direction for establishing permissible background vibration levels for residential and other settings.

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APPENDICES

1. Context and Instructions for the Workshop
2. The Notebook Organization

Context and Instruction for the ARCC-NSF Research Agenda Workshop

CONTEXT

The National Science Foundation's Division of Civil and Environmental Engineering has provided funding to the Architectural Research Centers Consortium (twenty-three of the nation's university-based architectural research centers, plus the American Institute of Architects Research Corporation) for the purpose of conducting a workshop on architectural research. The workshop, to be held in the Washington, D.C. area (Reston, Va.) on September 17 and 18, 1981, will formulate an agenda for architectural research within that division of N.S.F. Approximately 30 U.S. and foreign participants have been invited by ARCC's Executive Committee, based on individual expertise and experience in particular areas of architectural research. This effort represents a unique opportunity for the developing field of architectural research; it represents a potential continuing relationship between the interests of architectural research and the National Science Foundation. The agenda will not be all inclusive, but will illustrate fundamental architectural research issues or questions that fall into NSF's area of interest.

For convenience, the workshop will be organized into five general research areas:

1. The Process of Design and Construction,
2. Building Habitability,
3. Human Security and Safety,
4. Conservation of Resources,
5. Structural, Material, and Equipment Systems.

It is important that we understand that the National Science Foundation is concerned with basic and applied science and engineering. Science implies a body of knowledge and a systematic method of inquiry. Engineering implies the application of science in the service of man, in structures, systems, processes, and the like. The National Science Foundation is not a "mission agency"; it is not concerned with the applied, or problem solving, efforts that fall to other agencies such as the Department of Energy or Housing and Urban Development. Of course, this workshop effort relates to that part of architectural research that does relate to NSF interest.

Thus, the focus of this agenda setting workshop is on identifying fundamental research issues and topics that have a basis in scientific inquiry,--that fit into the context of basic theory building. This is not to suggest that we are interested only in classic scientific research models. Rather, we are interested in research in a variety of forms that fits into the overall context of theory building via hypotheses, deduction, observation, and inference.

Architecture is a broad, adaptive, and prescriptive discipline by nature of its purposes and methods. It brings together romantic and scientific views of the world. Serious and rigorous inquiry is an integral part of the field. And part of that inquiry involves the acquisition of knowledge from reason and laws, based on an appeal to objective evidence and on logical deduction and inference. Scientific research is a special form of inquiry which constructs theory or systematic explanations of how certain phenomena relate to each other, and which predicts future relationshps. The goal is to increase the understanding, and thus the predictability, of how things or people behave.

The establishment of fact in science is based on the simple question, "Do you see what I see?" That is, research findings must be universal; identical inquiries under identical conditions must yield the same results (empiricism). This universality of findings or replication requires a rigorous methodology; an accepted set of rules governs the process of gathering, analyzing, and presenting findings.

Scientific research methodology attempts to increase the validity and reliability of this form of knowledge acquisition.

STRUCTURE OF THE WORKSHOP AND AGENDA

The workshop and subsequent agenda will be organized into RESEARCH AREAS, each with some number of FUNDAMENTAL RESEARCH ISSUES, each with some number of RESEARCH TOPICS:

I. RESEARCH AREA
  A. FUNDAMENTAL RESEARCH ISSUE
    1. RESEARCH TOPIC
    2. RESEARCH TOPIC
  B. FUNDAMENTAL RESEARCH ISSUE
    1. RESEARCH TOPIC
    and so on.

RESEARCH AREA is here defined as a broad category of interest, illustrated by a number of key words or phrases, as follows:

I. THE PROCESS OF DESIGN AND CONSTRUCTION
  problem recognition and definition
  programming and analysis
  synthesis or design development
  building evaluation
  building industry performance, productivity
  construction process organization
  technology transfer/utilization, innovation
  work methods, efficiency, effectiveness
  flexibility
  preservation, adaptive reuse
  work methods
  process analysis
  computer applications
  standardization
  economic incentives
  education and training

II. BUILDING HABITABILITY
  use of buildings and complexes
  environment-behavior relationships
  space utilization
  worker productivity
  health effects of lighting, materials, use
  perception, cognition
  characteristics of user groups, special populations
  physiological comfort, satisfaction

human factors, anthropomorphic studies
plan, circulation efficiency
productivity-human, mechanical
evaluation

III. HUMAN SECURITY AND SAFETY
- building accident epidemiology and etiology
- intended, unintended use
- human factors, ergonomics, anthropometrics
- human responses to environmental conditions
- special populations as high risk groups
- natural and manmade disasters
- litigation and liability issues
- codes and standards
- design of entrance, egress, components
- instrumentation, safety systems

IV. CONSERVATION OF RESOURCES
- use of land, labor, capital, management
- supply, cost of renewable, nonrenewable resources
- comparative building economics, life cycle costing
- design for energy efficiency
- alternate energy sources
- economic forces of development
- technology assessment
- resource analysis

V. STRUCTURAL, MATERIAL, EQUIPMENT SYSTEMS
- systems choices and performance
- material use, characteristics, performance
- structural strategies
- system, component failure
- appropriate technology
- acoustics
- electrical
- lighting
- water
- heating, ventilating
- standards, codes
- building complex, infrastructure

The descriptors above are meant to be suggestive only; they are not inclusive or exclusive among RESEARCH AREAS.

A FUNDAMENTAL RESEARCH ISSUE is a basic question, substantive relationship, or method of analysis that requires our attention. It is a question that wants an answer, a phenomena that we need to understand, or a method that needs to be developed and tested. A FUNDAMENTAL RESEARCH ISSUE relates to an existing body of knowledge and to the building of theory that explains and predicts.

A RESEARCH TOPIC is a proposed research effort that fits under, or contributes to, a fundamental research issue. It is described as the subject to be researched, the method of inquiry, and the impact of the effort on theory and subsequent problem solving.

PROCESS

Again, the workshop will construct a research agenda consisting of the five RESEARCH AREAS, each with some number of FUNDAMENTAL RESEARCH ISSUES, each with some number of RESEARCH TOPICS. The process of building the agenda will be as follows.

1. Participants receive this material, including a set of one page forms. Lined forms are provided as worksheets; unlined forms should be used for typed versions (attach extra sheets as necessary). Several completed sample forms are included. Participants will construct five to ten FUNDAMENTAL RESEARCH ISSUES and related RESEARCH TOPICS. A priority ordering is not necessary; each identified ISSUE and TOPICS are assumed to be a high priority within the field of architecture. Many participants are forming mini-workshops with their colleagues to enhance the process, broaden the input, et cetera. Completed (typed) forms should be mailed to Jim Snyder by August 26, 1981.

2. These one-page forms will be copied and organized in some ordered way in loose-leaf notebooks, which will be distributed to participants at the workshop.

3. The workshop is organized into a series of small group workshop discussions, where sets of ISSUES and TOPICS can be reviewed, modified, developed, and so on. New ISSUES and TOPICS may be formulated. Participants will rotate through a number of small groups; results will be presented to and discussed with the group of the whole.

4. At the workshop conclusion, the staff will reorganize and edit the one page documents into the final report to N.S.F. Original materials and the edited report will be sent to all participants.

5. The completed report will be used by the National Science Foundation to clarify where architectural research fits into their interests. The format is designed specifically for that purpose, but should be useful to

architectural researchers in terms of formulating proposals that might be funded subsequently by N.S.F.

Please call Jim Snyder if you wish to discuss any part of our charge, and forward your completed forms to him by August 26.

Jim Snyder

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ARCC-NSF ARCHITECTURE RESEARCH AGENDA WORKSHOP

I. PROCESS OF DESIGN AND CONSTRUCTION

- **A. Economic Analysis**
- **B. Building Evaluation**
- **C. Computing**
- **D. Design Methods**
- **E. Design and Construction Process**

II. BUILDING HABITABILITY

- **A. Environments**
- **B. Environmental Systems**
- **C. Users**

III. HUMAN SECURITY AND SAFETY

- **A. Health**
- **B. Accident, Disaster**

IV. CONSERVATION OF RESOURCES

- **A. General**
- **B. Reuse**
- **C. Systems**
- **D. Economic Studies**

V. STRUCTURAL, MATERIAL, EQUIPMENT SYSTEMS

- **A. General**

Workbook pagination: Issue forms in the notebook are numbered by Area, Section, and Page. For example III-B-6 denotes page 6 within Section B of area III. Newly created forms should be numbered sequentially. Alternations and/or additions to existing forms should be subscripted with a,b,c, and so on; e.g., III B 6 a.

END

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AN AGENDA for ARCHITECTURAL RESEARCH 1982

ORIGINAL

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1982

a project of:
The Architectural Research Centers Consortium, Inc.

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PREFACE

The built environment, and the industry that creates the built environment, are vast. Incremental improvements in the ways we design and construct environments can have enormous total benefits. Yet, it is an industry without a strong tradition of research, -- in terms of research by, and for, industry participants. Architecture is a part of the built environment; the practice of, and education for, architecture includes elements of both science and design. While design is not science and not subject to scientific verification, it can be studied scientifically. The methods of science can be applied directly to much of the substance of architecture, and applied, as well, to improving our objective understanding of the processes of design and construction. This research agenda is designed to identify fundamental research issues and research topics in the discipline of architecture: research in the field of architecture, as well as research by others for the building industry. This effort is predicated on the belief that there are significant phenomena to be understood, methods to be developed, and theory to be formulated, -- to improve the quality of the built environment. Simply, architectural research is in our national interest and consistent with our intellectual heritage.

This Agenda for Architectural Research is the product of the individual and collective contributions of the forty-two persons who participated in the workshop process, and in many cases, colleagues from their home institutions. The process (described fully in the introduction) started with the submission of several hundred one-page research issues and topics. These were organized into a notebook; distributed, discussed, and modified in small group workshops (Reston, Virginia: September 1981); subsequently organized by discussion group leaders; and finally, edited into this document. Few issues or topics survived in original form; most have been restated, expanded or combined with other issues; some have been eliminated; some were newly created. However, I think it is fair to say that the tendency throughout the process has been to include as many issues as possible (even those not completely developed) and to alter substantive content as little as possible. We avoided the imposition of any strong organizing or editing scheme that would have affected the substantive content. Rather, the editing focused on a reasonable and simple division of issues, clarity of issues and topics, and elimination of the most obvious duplications. Thus, the product takes much the form of the original notebook. Some research issues and topics are developed almost to the form of preliminary proposals, while others are only notions or ideas. We trust that this form will be most useful to the field of architecture and architectural research, and to the National Science Foundation.

Finally, the editor must thank a number of persons who contributed most directly to the project. First, Michael Joroff and John Templer served as co-principals for the project and co-chairs for the Agenda Workshop, while Jim Haecker (ARCC Executive Director) directed the logistical tasks. John Archea, Robert Eury, Volker Hartkopf, Michael Joroff, John Templer, Chris Arnold, and Fred Krimgold led the small group discussions and subsequently organized materials by section. Both Gary Moore and John Templer provided material for the Introduction and Section Introductions. The NSF sponsors and participants were most helpful: William Butcher, Arthur Ezra, Michael Gaus, and Fred Krimgold. It was my pleasure to serve as project director and editor. As usual, errors and omissions of the final product rest with the editor.

James C. Snyder
1982

INTRODUCTION

Architecture and the Building Industry

The building industry is unique among the nation's industries. It is large, yet fragmented. The value of new construction put in place in 1980 is estimated to be over 200 billion dollars, of which buildings account for 147 billion dollars.[1] In 1972, the construction sector of the building industry employed three million persons and accounted for 61 billion dollars in corporate income.[2] At that time, there were over 130,000 general contractors, with the eighteen largest firms accounting for only 2.5 per cent of the total work volume. In 1977, there were nearly one-half million construction industries (contractors, subdividers, and developers).[3] And within the overall building industry, one must add consideration of the owners, users, architects, engineers, consultants, building officials, insurance and lending institutions, labor unions, and so on.

The building industry is composed of a large number of small, often labor intensive firms with local area markets. More than any other industry, it is modeled after the craft system, with each trade essentially self-employed. However, the industry takes this form with good (or at least apparent) reason. The fragmentation has several origins. First, building materials are heavy and often locally available. The efficiency of mass production does not offset the transportation cost for many building components. Components are shipped in basic form and fabricated near the building site. Second, the public regulation of building, and the institutions that finance development, exist at the local level. For these reasons, building firms find it most efficient to operate in local and familiar markets.

Each building project is a discrete event, with the major participants coming together in an ad hoc and temporary contractual relationship. The workload in a typical market is a function of national, regional, and local economic conditions. Thus, the workload varies considerably over periods of time and geographic location. Many building resources, and especially labor, are highly mobile in response to wide and unpredictable fluctuations in building activity. Firms contract or expand in response to market fluctuations, working on one or a few projects more or less sequentially. Risk is high; failure on a single project can mean failure for the firm. Firms are labor, rather than capital intensive, in an attempt to remain responsive to these conditions.

The architecture of a society is a physical articulation of that society's values and aspirations. It constitutes much of our built environment; it organizes space, time, communication, and meaning. The importance of the relationship between the built environment and how we perform, as individuals and as a society, is enormous. At another level, architecture is a product of the participants and processes of building; it is the product of the knowledge and methods used to design and construct buildings.

Typically, participants in the building industry include the owner, developer, user, architect, engineer, various consultants, building officials, lending and insurance institutions, general and specialty contractors, fabricators, and other indirect participants such as educators, researchers, unions, and the like. Because each project is a unique event bringing a mix of participants together, the roles of participants are governed by years of tradition and practice. Traditionally, the architect works as the agent for the owner, choosing the engineer and other consultants, and supervising the general contractor. These roles were relatively static until the recent emergence of a number of alternative organizational and procedural arrangements such as the design-build approach (owner hires a design-build contractor who employs the architect) and the construction management approach (owner hires a construction manager who manages the construction project). The point here is that we have seen the introduction of a wide variety of innovative processes for building in this last decade.

Architects, once confined to relatively specific and traditional roles in the industry, now find themselves in a variety of professional positions. There are about 60,000 registered architects in the nation, with about 40,000 in private sole proprietorships or partnerships. The remaining 20,000 architects work in agriculture, public administration, construction, manufacturing, education, finance, and numerous other sectors. Of course, one must add to these numbers those persons with architectural or related educations and working in the field that are not yet, or choose not to be, registered or licensed to practice.

Architectural firms, like other industry participants, are numerous and small. In 1972, there were just over 10,000 architectural firms in the nation, with over 5,500 firms employing less than four persons. Only 54 firms had more than 100 employees. Architectural services tend to include programming and other predesign services, schematic design, design development, preparation of contract documents, supervision of bidding, and the administration of contracts. However, firms often specialize in additional services such as urban design, interior design, adaptive reuse, and so on.

Education and training in architecture in the United States is the function of approximately 100 accredited university colleges and schools of architecture, and a larger number of technical or trade schools. These 100 university-based schools house about 35,000 architecture students. Most offer bachelor's and master's degrees in architecture; ten have Ph. D. programs. It is probably fair to say that architectural education focuses primarily on design and technology, with a strong emphasis or tradition in the studio experience. That is, a major educational effort occurs in an integrative design studio, where students work with faculty on various architectural design problems on an individual or small group basis. The remainder of the curriculum is composed of more typical lecture and seminar courses. This studio tradition has its origins in the Beaux Arts system in France, which existed from the 1800s to the 1950s, and in the Bauhaus in Germany from World War II to the present. The Beaux Arts system focused on study of the best of classic styles, while the later Bauhaus searched for unique solutions that were responsive to function, materials, and methods of construction. Architectural education in the United States was influenced by both, but followed primarily the integrative studio method of the Bauhaus from the 1950s to the present time. Although the design studio tradition remains dominant, architectural education in the U.S. has continued to develop in a number of ways. Consistent with general trends in university professional education, architectural schools have broadened the base of liberal arts. At the same time, most schools have increased the number of specializations within architecture; no longer is every student expected to be a building designer (e.g., urban design, urban planning, historic preservation, construction management, building technology, architectural research). Curriculums have also responded to an expanding knowledge base to include areas of applied social studies, environment-behavior studies, advanced technology, and the like.

Such a brief overview of the building industry, architecture, and architectural education is necessarily written with over-generalizations. Yet, it is meant to serve as context for the continuing description of architectural research. It should be clear at this point, however, that the industy is not structured in a way that supports major research efforts. Although the industry is large, and incremental improvements from better knowledge and methods could have significant impact, the industry is simply too decentralized to focus significant resources on research. The public sector, and specifically, university-based schools of architecture and engineering must take this responsibility.

Research in the Building Industry

Information about research activity within the building industry is as fragmented as the industry itself. Although one could ferret out some quantitative picture, that is not the purpose of this document. Suffice it to say that research is underrepresented in the building industry, relative to other industries, both currently and historically. During the early 60s, the ratio of research and development to value added in the construction industry was .12, in contrast to .43 for the economy as a whole.[4] In 1956, the construction industry spent 24 million dollars on R and D, --compared to 517 million and 461 million for the chemical and electrical equipment industries.[5] Construction industry scientists and research engineers numbered only 2,000 in 1960, -- compared with 36,000 and 62,600 in chemical and electrical equipment industries.[6] Although we have little current data, there is no evidence to support the notion that the research situation has changed. Simply, the industry is structured in firms, public agencies, and academia in a way that does not integrate research activity. There is no systematic industry-wide building of knowledge and theory. We are always surprised to learn how little we know about such a large industry with such a large impact on society.

Research in Schools of Architecture

However, we know more about research in the nation's schools of architecture. In 1981, the American Collegiate Schools of Architecture (ACSA) conducted a survey of research activities within schools, and determined that three-quarters of the schools were involved in research to varying degrees.[7] With projects beginning in the years 1976 through 1980, the 52 responding schools accounted for 164 projects worth almost fifteen million dollars. In addition, many schools are involved in significant levels of non-funded research.

There is a growing consensus among architects, engineers, researchers, and educators within the industry that the time for a serious committment to architectural research has arrived. In fact, the evidence suggests that architectural research is rapidly emerging as an integral part of the discipline. First, there is a growing awareness among building industry participants, and the public at large, that the built environment too often fails, -- in aesthetic, functional, social, and economic performance, and that the industry has not developed socially or technologically as well as other important national endeavors. There is a universal call for more and better information, and among educators, for more satisfying and useful theory. One reads of this concern in the popular press as well as in the architectural and engineering journals.

Reponses to this need for architectural research have come from primarily two sources: the university-based schools of architecture and several federal government entities. In 1976, the Architectural Research Centers Consortium, Inc. (ARCC) was created by member university architectural research centers and the American Institute of Architects Research Corporation to help promote the status and development of architectural research, to learn from one another's experiences, and the like. Twenty institutions now belong, of which only two have existed for more than fifteen years. The average tenure of these research centers is nine years. The yearly cash flows of these centers range from $200,000 to two million dollars, with full-time staffs from five to thirty-five persons. It is clear that schools of architecture have recognized the need for research and are responding institutionally via the establishment of research units and academic programs for research training. Schools have, or are in the process of making,

Table I - Dollar Volume and Number of Research Contracts 1976 - 1980

Research Area	Starting Date of Project			
	1976-1978 (mostly-ongoing)	1979	1980	TOTAL
Energy & Conservation	2,216,000 (12)	3,217,400 (26)	2,140,500 (28)	7,573,900 (66)
Computer Aided Design	439,000 (2)	177,000 (3)	975,800 (6)	1,591,800 (11)
Building Evaluation	25,000 (1)	359,000 (1)	65,000 (2)	449,000 (4)
Housing	496,000 (2)	403,000 (4)	285,000 (5)	1,184,000 (11)
Human Factors/Behavior	386,000 (2)	389,000 (7)	701,000 (11)	1,476,000 (20)
Building Codes/Regulations	--	21,300 (1)	83,300 (2)	104,600 (3)
Seismic Design	--	277,600 (5)	40,000 (1)	317,600 (6)
Facility Types	81,300 (2)	--	210,700 (2)	292,000 (6)
Technology/Construction	32,500 (2)	17,500 (2)	98,250 (5)	148,250 (9)
History/Preservation	--	827,350 (10)	82,200 (6)	909,550 (16)
Urban & Community Design	103,000 (4)	134,300 (5)	43,000 (3)	280,300 (12)
TOTALS	3,778,800 (27)	5,823,450 (64)	4,724,500 (73)	14,327,250 (164)

Compiled from ACSA Survey on Sponsored Architectural Research
(Washington, D.C. 1981)

research an integral part of architectural education. ARCC engages in a variety of activities in support of this trend, including site visits to schools, research seminars at conferences, this NSF Research Agenda Workshop Project, the National Endowment for the Arts funded Architectural Design Research Symposium (November, 1981), and the ARCC Architectural Research Industry Study (ongoing).

Other substantial support for the development of achitectural research has come from federal agencies, primarily in terms of research funding, but also in terms of cooperative efforts in structuring the field (e.g., this NSF Agenda, the NEA Symposium, the NEA Belmont Conference). According to the ACSA survey, major federal funding for research in schools of architecture came from DOE, DOD, AID, Administration on Aging, NSF, NEH, HUD, NEA, Department of Health and Human Services, Federal Highway Administration, GSA, NIOSH, NIBS (in descending order from $4,000,000 to $110,000), and to a lesser extent from a number of other agencies. In terms of ARCC developmental activities, NSF and NEA have been most supportive.

In summary, architectural research is woefully inadequate within the building industry, but within the context of a growing awareness of the need for research. Architectural research is a substantial and growing part of university-based schools of architecture, and is being increasingly recognized and supported by federal agencies.

The NSF Architectural Research Agenda Workshop

The National Science Foundation provided funding to the Architectural Research Center's Consortium for the purpose of conducting a workshop on Architectural Research titled: Workshop to Set an Agenda for Building Science Research Within the Program of the NSF Division of Civil and Environmental Engineering. The workshop was held in Reston, Virginia on September 17 and 18, 1981, with 42 participants. This report is the final product of the workshop project.

The details of the project purpose and process can be reviewed in the following appendices:

Appendix 1. Context and Instructions to Participants
2. The Notebook Organization (Original Form)

In short, however, the agenda process can be described as follows. Forty-two participants from universities, private firms, NSF, and other federal entities, including five participants from Canada, Sweden, England, and Japan, were invited to participate. Each person was given a set of instructions (Appendix 1) and asked to submit a number of one page **Fundamental Research Issues and Research Topics.** Many participants conferred with colleagues in this effort. These submissions were organized into loose-leaf notebooks which were available upon arrival at the workshop. After a plenary session, participants met in small workshop groups to discuss, accept, modify, and/or reject notebook entries, and to create new entries. Concurrent small group sessions were organized around the notebook contents (Appendix 2) over the two day workshop. Informal meetings and presentations by the foreign participants were scheduled also. After the workshop, small group leaders organized and partially edited their material and submitted same to the Project Director and Editor. The final product was organized and edited by the Project Director, reviewed by an advisory group, and reproduced in this form.

The Agenda

The Research Agenda thus assembled should serve as a useful articulation of a wide range of architectural research issues and topics. It should be useful to the building industry, and specifically to architectural practitioners, educators, and researchers, and to institutions that fund research. Although the Agenda represents a wide range of issues, it does not attempt to address all issues that can be subjected usefully to scientific inquiry. This in no way implies that other areas or methods of architectural research, or research issues not included herein, are not important, -- just that they were not included in this particular effort. Also, the issues and topics were not assigned priorities; all were assumed to be important.

The process of constructing an agenda was, in itself, a useful structuring exercise for the discipline. It should enhance communication within, as well as from, the discipline. Because of the singular process of construction and editing, the Agenda is essentially a notebook of issues and topics, simply arranged into five sections:

The Process of Design and Construction,
Building Habitability,
Human Security and Safety,
Conservation of Resources,
Structural, Material, and Equipment Systems.

Although obvious duplication between and within sections has been eliminated, these sections are neither all inclusive nor mutually exclusive. Undoubtedly, many important issues are neglected, while others exist in various forms in more than one section. Many topics are well-developed while others are interesting notions or ideas only. Finally, the extent to which this Agenda represents the field must rest with one's judgment of the representativeness of the participants. Representative inclusiveness and a satisfactory taxonomy of architectural research must await some future effort.

Michael Joroff
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I. THE PROCESS OF DESIGN AND CONSTRUCTION

A. Design and Construction Process

B. Design Methods

C. Building Evaluation

D. Computing

I A THE PROCESS OF DESIGN AND CONSTRUCTION: DESIGN AND CONSTRUCTION PROCESS

Introduction

This section addresses research issues related to the processes of design and construction, including:

1. **Insrumentation and Measurement**
2. **Comparative Evaluation of Design and Construction Processes**
3. **The Role of Organizational Structure**
4. **Relationships Among Aesthetics, Architectural Practice, Clients, and Users**
5. **Self-Help Processes in Housing**
6. **Risk Distribution in the Design and Contruction Process**
7. **Comprehensive Uncertainty-Risk Analysis**
8. **Building Regulation and Habitability**
9. **Technology Transfer**
10. **Relationship of Design to Construction**
11. **Building Construction and Environmental Damage**
12. **Contextual Fit in Architecture**
13. **Meaning and Symbolism in Architecture**

I A 1 Research Issue: Instrumentation and Measurement for Architectural Research

One of the fundamental problems of architectural research is the absence of relevant, quantitative data. Relevant measurable indicators for many critical parameters remain to be identified. Methodological problems are serious in every subject area of architectural research. The "case study" or "investigation" is prelude to more rigorous methods of study. Advancement beyond the intuitive, descriptive case study to a more rigorous and quantitative recording of observations, allowing for comparison between cases and controlled experimentation, is essential for the progress of the discipline.

Measurement and instrumentation are intricately intertwined. You measure that which your instrument registers. Ability to measure increases with the development and improvement of instruments. Architectural research should decide what it needs to measure. What are the critical variables of interest for architectural researchers? How adequate is their measurement? What instruments, tools, and scales are needed? Expanded measurement capability is fundamental to the advance of science and theory in this area.

The following examples point up a basic characteristic of architectural research, namely that the object of study is large, rarely portable, and often difficult to study in a conventional laboratory. This means that much research must be carried out on site. Instrumentation and methods must accommodate site conditions. Test methods often must be non-destructive and even non-intrusive because the object of study is in use. This is a general and overriding issue, -- it is not topical nor is it limited to "design and construction process."

Research Topic

1. The development and testing of portable instruments to measure physiological response to buildings on site, or characteristics of building environments (indoor air pollution) on site.

I A 2 Research Issue: Comparative Evaluation of Design and Construction Processes

The methods by which buildings are planned, programmed, designed, bid, and constructed tend to be accepted in traditional forms. Alternate processes ought to be examined to optimize economy of construction and efficiency of use.

Research Topic

1. Various methods of building acquistion exist: (1) design-bid-construct, (2) construction management, and (3) design-build, for example. Case studies could be utilized to describe the characteristics of various methods and their effects on time, cost, owner's satisfaction, architectural merit, and the like, with respect to building type, economic conditions, and so on. This would include the development of innovative processes, parameter description for case studies, estimation of consequences of various innovations, and the identification of material-process and process final architectural product relationships. In particular, the dysfunctions of traditional process would be explored. All of this would lead to testing the hypothesis that process effects product, and to the building of a theory of building process. The effort should move from initial case studies to empirically-based models.

I A 3 Research Issue: The Role of Organizational Structure in Promoting Better Design

Buildings are usually designed and constructed by teams of professionals who come together for the first time for the single project. Often, their designs are characterized as overly conservative and lacking in innovation. This is particularly true in areas which lack design performance measures, such as in transit projects. Better understanding of the role of organization structure in promoting better design could lead to design team evaluation methods and the design of better organizations.

Research Topics

1. The location of key communication functions within an organization affects the quality and innovativeness of a design product. Location and communications between "gate-keepers," "coaches," "idea generators," et cetera could affect the level of risk aversion and of perceived risks and should be important in a multi-firm project team. Reasons for effective versus ineffective project teams must be developed for future team selection or team design. Case studies are most likely required for this work.

2. The impact of "accepted practice" on design methods needs to be assessed. Using a decision analysis method, this work should assess costs and constraints to innovation impacts caused by the actual or perceived basis for legal liability being related to accepted practice. Impacts of other bases for determining liability for failures must also be assessed.

3. The topics above would involve investigation and development of design performance criteria and measures, critical sequencing and time determinants in the design process, and conceptual-descriptive models of various processes (supported by case studies and broader survey research).

I A 4 Research Issue: Fundamental Relationships Among Aesthetics, Architectural Practice, Clients, and Users in the Building Process

A fundamental question in architectural research in terms of professional tradition is the objective evaluation of aesthetic quality. While this problem may not be as central to architectural research as it is to current architectural education, it is, nonetheless, important. A scientific approach to the understanding of aesthetics could be of great interest and value. Current discussion of architectural aesthetics is extremely imprecise and limited.

This issue raises a further set of fundamental questions on the responsiveness of the building process, building technology, and the design profession to social and economic change. At present, in the absence of an established empirical analysis of social and economic factors, the building industry is assumed to respond to a market. The market for buildings happens, however, to be very specific and very different from markets for other products. Factors of time, mobility, and scale of investment pose major constraints on the responsiveness of the building market. Generally, if design is to respond to demand (some expression of user needs), engineering and architecture must develop sophisticated methods for surveying and analyzing demand, particularly as it changes over time. Changing patterns of demand have profound implications for the "adequacy" of technology, as the adequacy of technology is defined by the fit of supply and demand.

Engineering and architecture, in different ways, have tended to over emphasize "innovative modification" of the supply of technology without rigorous understanding of effective demand. If building technology is to respond appropriately to social pressures, an important role of architectural research is to gain understanding of those social pressures and their implications for building demand. This problem is particularly serious for building because initial investments are great and product life is often assured to be on the order of forty to eighty years. Committment of major social investment over such a period of time requires sophisticated analysis and projection of relevant social patterns. Such analysis is important to establish a balance of generality and specific accommodation in buildings.

Research Topics

1. The objective measurement of aesthetic quality should be approached within a scientific framework, from conceptual structuring through case studies and theory building.

2. The supply and demand of architectural services, -- basic inquiry into the growth of the knowledge base of architecture, relationships among aspects of professional training and professional qualification, and licensing practices, -- all in relation to the profession's response to the demands for services. What does society demand, and how is the field organized to respond? What role does the knowledge base play? Can this information be linked to theory?

3. The social and political context of design. The built environment is a physical expression of social phenomena. Architects and engineers overcome physical obstacles to give expression to social value. Yet, we know little about the impact of social and political factors on the supply, demand, and quality of the built environment. We need a variety of explorations in this area. For example, what is the relationship between building technology and social development? A lack of understanding of the limits of disciplinary expertise leads to misunderstanding, disappointments, and a loss of credibility for architecture.

4. Clients and user groups. What are the design implications of various client and user group structures? Design often operates on the assumption that complex values and objectives are contributed by an informed client, -- often standing in for a subsequent user group. Yet, projects of any scale usually involve multiple client and user groups with

multiple and conflicting values. Many design failures can be traced to a failure to synthesize and articulate explicit multiple criteria. We need to understand designer-client-user dynamics, (group dynamics and decision processes) and to develop better systematic methods for addressing those relationships in the design process, especially for multiple objective and multiple use situations.

I A 5 Research Issue: Self-Help Processes in Design and Construction, Especially in Housing

The housing market is witnessing a significant trend in self-help housing. Price inflation and high interest rates have accelerated the incentive to homeowners to use local labor and material technology to save on new construction and alteration. Although many owner built houses exhibit innovative uses of appropriate technology, many have had deleterious effects on occupants and neighborhoods. We need to understand the processes of self-help architecture, and assess the effects, -- both good and bad. The fundamental issue is the relationship between the process and the quality of the product.

Research Topic

1. Survey and evalution of self-help housing. We need to examine the self-help housing phenomena via a survey of self-help efforts, individual and organized, and assess the costs and benefits of the products, including those accruing to owners and community. This would include the development of an appropriate evaluation methodology, and the aspects of aesthetic values, indoor air quality, materials effects, energy consumption, codes and regulation, financing, et cetera.

I A 6 Research Issue: Risk Distribution in the Design and Construction Process

The production of a constructed facility such as a building involves a large number of people and organizations, organized traditionally around the client, the designer, and the contractor. Each party has its own perception of the nature and magnitude of the risks involved in the project and the extent to which certain risks are controllable. Contractual terms and regulations allocate risks to the various parties, each of which seeks an economic return commensurate with bearing each type of risk. Fundamental questions include the current distribution of risk and legal liability and the effect of that distribution on the final product. Are decisions overly conservative; does practice reflect reality?

Research Topic

1. This work involves development of an empirical risk allocation prediction model which can accept as input data on risks and risk perceptions by different parties, their risk profiles and their perceptions of the impacts of risk allocation clauses. This can become a tool for the study of contract terms, the cost effectiveness of risk mitigation schemes and costs associated with the fragmented nature of the industry. Data could be collected via case study interview and project review methods, as part of a theory and model building effort.

I A 7 Research Issue: Comprehensive Uncertainty-Risk Analysis Methodology for Design Decision Making

Although we recognize the stochastic nature of the environment for which we plan and design, our engineering and planning is performed almost exclusively as if our world were deterministic. With differences

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in perceived and actual levels of risk and different levels of risk aversion among professionals, we recognize that planning, design, and construction decisions might differ if uncertainty and risk could easiily be included in the decision process. What is needed is a comprehensive risk analysis methodology for decision-making under uncertainty.

Research Topics

1. Develop a methodology for integrating traditional judgment, subjective and historical data with the evolving state of the art in research. Provide an intellectual framework for accumulating experience. Evaluate, systematically, the judgment of design professionals relative to ability to predict outcomes. Identify major areas of uncertainty.

2. Development of a model framework of design and decision options or alternatives. Given the characteristics of required decisions and their interrelationships, together with risk-based data on the probable outcomes of decisions, such a system will help sequence decision processes and maintain alternatives that have a significant probability of becoming best.

   Such models are useful in decisions on the trade-offs between slower design/construction versus more conservative interface requirements as typified by fast-track construction or in evaluating the risk and rewards from adaptable (design during) construction.

I A 8 Research Issue: Building Regulation and Habitability

Is there a correlation between building regulation and building habitability (affordability, accessibility, etc.)? Or, how has building habitability been affected by regulations which seek to control the amount, size, and quality of space provided in various building types?

Building regulations have been established in an attempt to assure certain minimum safety standards in both public and private building. There is some question as to whether these regulatory processes and criteria have, in fact, improved building habitability. It is possible to test this hypothesis through the observation and measurement of building habitability in both regulated and non-regulated situations.

Research Topic

1. Effects of regulation on habitability. Particular building types have come under heavy federal, state, and local regulations (chiefly buildings such as mobile homes, nursing homes, day care centers, etc.). It is possible, however, to find examples of these building types in non-regulated situations. Through direct observation and questionnaires, it would be possible to compare facilities along certain measurable categories to observe the difference in degree of performance and satisfaction between regulated and non-regulated buildings. This research would provide new insights into the actual effects of regulatory provisions in creating habitable buildings. This assumes initial work in terms of developing meaningful definitions of "habitability."

I A 9 Research Issue: Technology Transfer and the Building Process

The fragmented nature of the building industry requires that knowledge flow among a variety of disciplines and organizations, including researchers, educators, product manufacturers, developers, architects, engineers, builders, trades, -- to name a few. The transfer of technology is extremely important. We need to understand the process of introduction and transfer of technology in the building industry.

Research Topic

1. What is the process of technology transfer among segments-actors in the industry, including transfer among disciplines such as architecture and engineering? What is the rate of transfer? How effective are the methods? How do we measure successful transfer? Basic conceptual modeling and insight are needed first, via case studies, followed by definition of critical variables, conceptual modeling of these variables, development of measurement techniques, and eventually, empirical verification and predictive modeling.

I A 10 Research Issue: The Relationship of Design to Construction

Buildings are seldom constructed to the exact formal specifications of the architect. Often, intentional and unintentional changes take place at the time of construction, due to unforeseen problems, local building convention, materials substitutions, inadequate inspections, and the like. However, we know little about the acceptable variation between design intentions and as-built structures. In critical cases, we find death causing failure. What is the margin of error? What systems of quality control operate? How well do they operate?

Research Topic

1. Estimation of variances between intentions and as-built construction. We need to examine a sample of buildings and building situations in order to describe quality control systems and variances between intentions and product, and evaluate the effects and potential effects (positive and negative) of these variances. We need to compare these findings with the experiences of other countries with different control systems. We need to explore alternate (industrial) quality control systems, including control and decision theory.

I A 11 Research Issue: The Relationship Between Building Construction and Environmental Damage

The environmental impact of building construction has been an important architectural issue for more than two decades. Fundamental questions include methods of impact assessment, the prediction of impacts for particular projects, and methods of design and construction that minimize environmental damage.

Research Topic

1. We need to develop useful measurements of environmental damage due to building construction, and models that predict damage on the basis of currently available data. Secondly, we need to use the above information to explore modifications to building processes that would minimize detrimental impacts, or perhaps enhance environmental quality.

I A 12 Research Issue: Contextual Fit in Architecture

A fundamental architectural question involves the way a particular buiding "fits" into its community context. In recent years, the relative fit of a proposed building has become a very important design consideration; project designs are approved or rejected on the basis of "fit" as perceived by clients, community groups, adjacent owners and residents, and so on. Yet, we know very little about contextual fit. What is it? How is fit perceived? How do we measure it? "Fit" is a useful concept without an explicit, objective base. Yet, a number of dimensions are apparent: economic, social, political, style, scale, and so on. We need an objective basis for this important concept.

Research Topic

1. Basic conceptual structuring of contextual fit concepts and case studies of buildings in terms of contextual fit, including multiple dimensions of fit, criteria, measurement, and eventually, predictive models and design theory.

I A 13 Research Issue: Meaning and Symbolism in Architecture

One of the most significant of recent trends in architecture is the increasing tendency among leading architects to design with the conscious intention of manipulating not only form but also the meanings evoked by that form. The essence of the argument to which these practitioners, as well as a number of theorists and critics, subscribe can be summarized as follows. An essential aspect of people's interaction with buildings is the meanings they associate with those buildings. Good design, therefore, should encompass a conscious manipulation of intended meanings. That buildings can and do hold a variety of meanings for people is clearly substantiated by the research of psychologists, sociologists, and anthropologists. But without more intensive testing of specific building forms, there is no way of knowing that the symbols and historical allusions that architects are now so enthusiastically incorporating in their designs will have any relevance to the people they are designing for. Although this is not a scientific question per se, it is a question that can be approached from a scientific basis.

Research Topics

1. Meaning in contemporary architecture. The object is to test empirically the extent to which those buildings which have been designated with a conscious intent to evoke particular meanings actually do so successfully. The meanings evoked by a variety of recently completed

buildings would be elicited through systematic interview procedures administered to a wide cross section of people. The result would be to identify particular aproaches to design which hold promise for generating architecture that is meaningful and symbolically appropriate to its users.

2. Ethnic and cultural variations in meaning. The manner in which people interpret a particular building or environment is, at least in part, a function of their social or cultural experience. The variations of meaning across a set of buildings may be explored in the context of several distinct ethnic and socio-economic groups. The results would help to clarify for architectural practitioners the expected range of interpretations that design may generate.

I B THE PROCESS OF DESIGN AND CONSTRUCTION: DESIGN METHODS

Introduction

This section addresses the need to systematically examine the processes whereby we design and construct buildings. Fundamental issues include the efficiency and effectiveness of traditional methods of architectural education, the intuitive decision-making behavior of designers, and the investigation of factors that influence design and construction: information, style, criteria, analytic methods, and legal constraints.

1. **Models of Architectural Education**

2. **The Problem Solving Behavior of the Individual Designer**

3. **Environmental Information**

4. **The Continuing Importance of Architectural Style**

5. **Buildings as Systems**

6. **Planning and Design Criteria for Industrial Facilities**

7. **Analytic Methods in the Building Industry**

8. **Institutional and Legal Impacts on Design Process**

I B I Research Issue: Models of Architectural Education

Architectural professional education is a long, expensive, and labor intensive process, based heavily on the studio method. This educational system substantially affects the practice of architecture, though the process has remained substantially unchanged for three hundred years.

Are there better models? Can the present model be made more efficient? Can other models of professional education (e.g., engineering, law, medicine) significantly expand the range of issues and the knowledge of building?

Research Topics

1. Alternative educational models. Identify and evaluate alternative models of architectural education within schools and between schools of architecture, especially with respect to the scientific and other bases for professional practices.

2. Teaching architectural skills. Identify specific skills taught in schools of architecture; explore the application of new technology to teaching skills.

I B 2 Research Issue: The Problem Solving Behavior of the Individual Designer

There is a voluminous literature on design methods and computer aided design, but very little of it is based on the psychology of how designers actually behave in problem solving situations. Architectural research is just starting to investigate this subject. Based on past research, the variables that have had a demonstrated impact on how designers work can be categorized into three broad subject areas. (1) The individual's education, personality, and skills influence design behavior. Some designers are more analytic; others are more intuitive. Some have had considerable formal education, and others have had more on-the-job training. (2) The architect's environment also constrains design behavior. Offices are organized and managed in different ways. Different lines of authority influence design behavior. The use of design teams is significant. Even the architect's social ties influence design behavior. (3) The scope and complexity of the specific architectural problem also influences actual design behavior. Some problems have tighter financial constraints. Others have more complex and innovative programs. Still others have important political considerations. The field for investigation is quite large, but the issue is clear. We have very little scientific knowledge about how architects really solve design problems. Without such investigation it is difficult to expand our overall knowledge and theory of architecture.

Research Topics

1. Differences between design process intentions and realities. The architectural profession well recognizes the difference between design intentions and final results. Most often the assumption is that legal and economic constraints account for the difference. We do not know to what extent the problem solving behavior of designers accounts for the difference. Research can address this issue by systematic interviews of architects; analyses of situations where the architect's expectations were realized or unrealized; correlations between differences in expectations and differences in the architect's problem solving behavior, personality, type of office or managerial setting, and type of problem being solved. This information will increase our basic knowledge about how architects perceive the design process, about the psychology of design, and about ways to improve the overall design process.

2. Moral and ethical dilemmas in the design process. History and contemporary architectural magazine literature record the dilemma faced by architects involved in controversial projects. Little is known about how conflicts are confronted and resolved, and about the impacts of dilemmas on the rest of the design process and on the built environment. Research methods could include interviews of architects throughout design projects, identification of conflicts between personal values, perceptions of client needs and values, societal values, et cetera, and specimen recordings of how conflicts are dealt with and resolved. Content analyses can be conducted and the results correlated with

differences in the architect's individual experience and social background, office management system, and the type of problem addressed. The impact will be to increase our understanding of how architects actually behave in response to moral and ethical problems. This is especially relevant as the scope and complexity of architecture increases.

I B 3 Research Issue: Environmental Information

How do people acquire information about the built environment? How do they store that information, and how do they recall that information for use in making plans to use that environment? Such questions relating to the cognition process by which mental maps of the environment are formed need to be described and understood. This knowledge can be important in understanding how users of buildings respond to the built environment, particularly in times of stress.

Research Topic

1. How do various building configurations affect the ability of users to find their way in complex buildings? How do factors such as the visibility or exposure of areas and activities affect their use or nonuse? What cues do people use to identify buildings or areas within buildings as belonging to a particular class? What are the visual search patterns that people use in various types of settings that require complex decision-making such as lobbies, corridors or approaches to buildings? Unobtrusive observational studies and controlled experiments in various building settings would contribute to theory building in this area.

I B 4 Research Issue: The Continuing Importance of Architectural Style

For all the efforts to rationalize the architectural design process, we have seen in the last three decades an architecture dominated by style, at the expense of economic efficiency, energy conservation, habitability and seismic safety. The current thrust of advanced architectural design practice appears to be moving even more strongly in an individualistic, irrational, and user indifferent direction. Fundamental thinking is necessary about the relationship between style and other architectural parameters.

Research Topic

1. The role of style in architectural design. Studies in the recent history of style (detailed, interdisciplinary; respecting technology, economy, and the practitioner, rather than the historian only) including the relationship between style and other parameters in the design process, could lead to improved architectural design theory, and the appropriate integration of the more intangible factors affecting design.

I B 5 Research Issue: Buildings as Systems

Buildings are designed as an integrated series of systems and components, each designed by a different professional and installed by multiple trades. The productivity in construction can be affected very strongly by the interactions and interfaces between components and systems. Methods are needed to predict the probable conflicts for space among systems within buildings early in the design process to promote better space allocation. Methods are also needed to predict cost and schedule impacts of component interfacing details.

Research Topic

1. There is a need for a model structure which identifies construction requirements and sequences for each speciality trade during design. The model must forecast spatial and connection requirements, and be updated as the design becomes more detailed. This requires methods for describing the interfaces between components and forecasting construction effort and sequences based on joint characteristics; it must produce a construction schedule (probably line-of-balance type) and estimate, and a log of physical conflicts. Such a system should become a guide to effective interdisciplinary computer aided design.

I B 6 Research Issue: Planning and Design Criteria for Industrial Facilities

The architectural design process depends heavily on planning and design standards and guidelines that are organized by major building type. Although such material exists for many building types, there is little or none for industrial facilities; the issue is equally important for new and rehabilitation projects. Given the importance of industrial building, and especially rehabilitation, it seems important that the field generate this information, in a guideline or an alternate form.

Research Topics

1. Industrial building typologies need to be developed initially. This could be done through extensive field work and through interviews with design professionals. Selected building and site characteristics for each type would be identified. Representative samples of each type would be selected and the characteristics would be collected. This data base would be updated and used as an empirical base for design guidelines.

2. Identification and evaluation of the effectiveness of standards and

guidelines; development and testing of alternate forms of storing and accessing this information, using industrial building type data as the focus.

I B 7 Research Issue: Analytic Methods in the Building Industry

Development of organized building diagnostic methodologies for extending analytical tools in environmental design to the community of building architects and engineers. There are a number of potential areas where the development of such a diagnostics capability would be applicable.

Research Topics

1. Development of a building diagnostics capability based on the use of a controlled environment chamber (device for simulating varying lighting and thermal conditions within an actual or replicated office space). The object would be to extend quantitative measuring capabilities to include variables of direct interest to designers and building owners. A specific focus could be on workplace productivity impacts of varying lighting and thermal comfort levels, as well as different approaches to the control of lighting and thermal comfort.

2. Development of a diagnostics capability based on microcomputer software programs that can help builders, designers and government agencies thoroughly consider potential environmental impacts of site development and building construction, draw attention to an identified range of mitigation measures for each potential impact, help make decisions about which measures are most appropriate, generate cost implications of different choices, and the like.

3. Development of field methods for testing lighting and thermal comfort

levels in large commercial buildings. This effort would represent a refinement of existing field methods for testing residential buildings. This would be an important step in calibrating a controlled environment chamber.

I B 8 Research Issue: Institutional and Legal Impacts on Design Process

We need to understand more fully the nature of various institutional and legal impacts on the design process and the subsequent built environment. The efficiency of our built environment may not be as much a problem of technology and art, as a function of social, institutional, and legal constraints on design and construction. Also, what is the technological base for our legal constraints?

Research Topic

1. Systematic assessment of institutional and legal factors affecting the design and constructing processes, including case history and field investigations. Also, what is the technological basis for major legal constraints?

I C THE PROCESS OF DESIGN AND CONSTRUCTION: BUILDING EVALUATION

Introduction

It is generally acknowledged that we can no longer build environments in precisely the same manner in which we have done so in the past. More and more people are unwilling to accept the indiscriminate use of land and other resources which are diminishing in availability and rising in cost. At the same time, the mistakes in building which result in unforeseen economic and social costs and loss of life are viewed as intolerable by the public. Procedures are therefore needed to improve the planning and design process so as to (a) optimize resource utilization, (b) minimize the costs of building, and (c) create more humane and safer environments. One way of achieving these objectives is by systematically learning from our past efforts. Careful evaluations of built environments and plans for such environments can inform the design professions about the degree to which their creations and proposed creations have or will fulfill objectives related to building economics, systems functioning, and life safety. Information derived from such systematic evaluations can be used as a way of modifying the environment under study and as input into predesign, making for new environments.

Building evaluations have been conducted in Europe and the United States since the early 1950s. The best known of the early evaluations were conducted by the Building Research Station in England and later by Building Research Institutes in Sweden, France, Australia, and elsewhere. Most of these early evaluations focused on housing from social and economic points of view, while others concentrated on public outdoor space, parks, and new town developments. A well-known series of evaluations was conducted of schools by the Building Performance Research Unit in Scotland in the 1960s. As with most European evaluations, the focus was on technical, functional, social, and economic issues.

By contrast, building evaluations in this country have been conducted either by building authorities or by university research departments. Many evaluations have been conducted by managers at HUD-assisted housing and by research psychologists, sociologists, and, more recently, research architects from university settings. The academic-based studies tend to look at a narrow range of issues, but look at them in great depth; for example, the impacts of different housing configurations on security, comfort, spatial mobility, friendship patterns, privacy, and isolation in the elderly. By contrast, the management-based evaluations tend to look at a broader range of issues (technical, social, economic, management, and design) but in a more cursory manner. The university-based research is more rigorous, theoretical, and scientific, while the management-based evluations tend to be informal case studies to answer pragmatic questions. Currently, both the Department of Housing and Urban Development and the National Bureau of Standards are interested in the systematic evaluation of buildings in use.

Architectural building design, and urban design in this country have been notorious for their lack of a scientific base. Decisions about the configuration of housing, the layout of communities, the height of buildings for the elderly, the role of the environment in ameliorating handicaps, et cetera, have been based on oral traditions passed down from principles to associates in firms across the country. Much of these oral traditions undoubtedly have validity, while other "rules of thumb" are incorrect and have been found to lead to disasterous effects. The recent development of building evaluation in this country has been an attempt to place building design on a scientific foundation by assessing the impacts of different management, economic, design, and construction decisions on outcomes of user satisfaction, structural stability, and economic viability.

At the same time as serving this pragmatic social function, building evaluations contribute to our overall base of knowledge about buildings in use -- how they function in the field rather than in the laboratory, how people respond to actual designs, how different configurations contribute to energy savings, how design decisions contribute to health and safety, et cetera. Together with more theoretically inspired research, research on buildings in use is seen as a major contributor to architectural knowledge.

As stated in a recent report from the National Endowment for the Arts, "Whenever design is done poorly, when intended purposes are not met and/or new programs are created, we incur human and/or economic costs . . . Some costs are very obvious, such as a set of outdoor steps in a public place badly proportioned and poorly lit, which becomes the target of several costly accident lawsuits. Some costs are less obvious, such as the poorly balanced power tools that fatigue the hand and arm, requiring frequent rest periods, or the poorly planned hospital that forces its highly-paid medical staff to walk excessive distances, using time and energy non-productively . . . Other costs generated by poor design are not obvious or easily calculable, but are very real to those who bear them. The elderly frequently avoid certain activities because they are risky . . . denying them activities that can enhance the quality of their lives; it is a cost they must pay."[1]

Economic analyses have been made of hospitals, offices, and housing that show that the monetary costs associated with building design mistakes are far greater than the costs of more appropriate and supportive design. The ratio of labor costs to building-related costs is about 14:1 over a 25 year period; with these ratios it becomes clear that to the degree that appropriate environments support worker productivity and satisfaction, supportive architectural design can have strong multiplier effects. Building evaluations aim to uncover the dimensions of productivity, building use, and satisfaction so as to improve subsequent building design and construction and increase the multiplier effect.

Building evaluation research has had marked impacts on public policy and professional practice in Europe; this impact is beginning to be felt in the United States. For example, building evaluation research conducted in England and Sweden found a stable relationship between height of residency above the ground floor and children's use of public outdoor space. This research led to national legislation restricting the height above ground that families with children could live, and has had a long range impact on building height in high density residential areas. The results of evaluation studies are published regularly in the form of design bulletins and have become standard operating procedures in professional offices. The impact of post-occupancy research in the U. S. A. has been slower, but is beginning to be felt primarily in the public sector where a number of federal agencies are advocating evaluations of buildings in use (General Services Administration, National Bureau of Standards, Department of Housing and Urban Development, National Institute of Building Sciences).

This topic area has tended to be organized around environmental setting types, for example, community design, housing, recreation environments, housing for the elderly in particular, and so on. To date there is no clear conceptual structure to the topic area. Differences exist, nevertheless, between case studies of one building and cross-sectional studies of many buildings of the same type (e.g., the evaluation of twelve HUD-assisted housing projects across the U.S.), between informational methodology and rigorous procedures (e.g., extensive surveys and multi-variate analyses), and between studies aimed at uncovering basic knowledge and contributing to architectural theory (e.g., studies of the relationship between office design and productivity, or between hospital design and recovery rates).

As seen by the leading researchers in the area, the time is now to move beyond single case studies with informal methods to rigorous, comparative post-occupancy evaluations using the best research instruments, procedures, and data analysis procedures available.[2]

The fact that the area is structured neither conceptually nor methodologically suggests the major areas of weakness and unaddressed issues. As suggested by the participants at this workshop, the issues are of three major types:

a. Characterizing the Effective Environment

There is little scientific agreement on how to compare findings across building types, how to transfer findings from one case study to another setting, and how to define the critical environments to be evaluated. This has delayed systematic accumulation of knowledge and development of theory. There are two complementary approaches to rectifying this problem: (a) the development of a nominal typology of building types to assist comparisons and transfer (e.g., high rise, mid rise, low rise; linear, non-linear; open, closed; etc.); and (b) the development of an agreed-upon systematic classification of critical environmental variables (i.e., those architectural variables found to have impacts on a range of social, economic, and structural behaviors). Both developments require creative conceptualization followed by rigorous empirical investigations. The result would be a system of environmental variables that can be used as independent variables in subsequent evaluations across a range of buiding types.

b. Developing Appropriate Assessment and Measurement Instruments

As mentioned, most building evaluations in this country to date have been informal in research design and have thus not been able to contribute to the systematic accumulation of knowledge. A major reason for this problem has been the lack of rigorous and agreed-upon instruments for measuring outcomes. A variety of survey research instruments have been employed incorporating a wide range of scales and tests. The task now is to systematically decide what instruments are the most appropriate for measuring outcomes (e.g., for measuring productivity, performance, and satisfaction) followed by the empirical development and test of those instruments. We need to know what the critical variables of success are. We need to develop instruments for evaluating social, economic, and technical factors, and for allowing the comparison of these variables in whole buildings.

c. Systematization and Testing of Findings

From the over 1,000 building evaluation studies conducted in this country, there is a wealth of available data on successes and failures. Emanating in part from these evaluations are a plethora of perhaps close to 100 planning and design guides on a range of building types. With the exception of partial reviews of this literature,[3] and with the exception of a few attempts to produce interwoven design guides,[4] there has been little systematization of these case study findings and subsequent testing of design recommendations emanating from them. Some current research supported by NEA is perhaps the first in the country to evaluate the effectiveness of design recommendations emanating from previous evaluations. We need to support the systematization of findings for different building types, and the subsequent testing of design recommendations put into practice in subsequent buildings.

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1. Methods for Assessing the Impact of Architectural Design on Occupant Performance

2. Pre-Occupancy Evaluation

3. Objective Measures of Spatial Organization in Architecture

4. Environmental Patterns

1. M. Brill and M. Villecco. *Environmental/Design Research: Concepts, Methods, and Values.* Washington, D.C.: National Endowment for the Arts, 1981.

2. *Progressive Architecture* Annual Awards Issue, January 1982 (in press).

3. R. Bechtel and R. Srivastava. *Post-Occupancy Evaluation: Final Report on HUD-Assisted Housing*. Tucson, Arizona: Environmental Research and Development Foundation, 1978.

4. Series of design guides for military facilities, supported by the U.S. Army Corps of Engineers Special Projects Section, Office of the Chief of Engineers, Washington, D.C. between 1976-1981.

IC I Research Issue: Methods for Assessing the Impact of Architectural Design on Occupant Performance

Generally, systematic assessments of the effects of architectural design on the performance and well-being of building occupants or users are not conducted. As a result, the designer's knowledge base is neither cumulative nor self-correcting with regard to the primary missions of building or building programs. Although a number of architectural researchers have conducted post-occupancy evaluations (POEs) of completed buildings or building complexes, very little of this research addresses the major architectural options considered during the design process. In addition, there is wide variation in (a) the type of data collected, (b) the sources from which it is obtained, and (c) the scheduling of data collection throughout the design-construction-occupancy sequence. However, if the most salient links between architectural variables and occupant performance can be identified and standardized evaluation formats can be established, then post-occupancy evaluations can provide the architect with a very useful tool for accommodating the functional requirements of building programs, -- systematically tying each design decision to knowledge of the effectiveness of prior decisions.

Research Topics

1. Identify major architectural factors that are consistently found to be predictors or indicators of occupant performance in buildings. Sampling and measurement methods for these variables should be calibrated and validated for use under a variety of field conditions. Additional procedures should be developed for identifying innovative design features or unusual operating conditions that could yield significant new performance data if subjected to intensified or prolonged evaluation.

2. Identify critical data collection needs and sampling intervals for the design-construction-occupancy sequence. In order to maximize the

reliability of pre- and post-occupancy data collection, researchers need to know when critical design decisions tend to be made, how far in advance organizations tend to adjust to an impending relocation, and how long after the move occupancy patterns begin to stabilize for various building types.

3. The effectiveness of systematic evaluations for enhancing the decision-making abilities of designers and for improving occupant performance in buildings should, itself, be evaluated. Distinctions should be drawn between benefits realized by the architects, the owner/client, and the occupant/user. The benefits of post-occupancy evaluation must be demonstrated to those involved in the design and use of buildings.

IC 2 Research Issue: Pre-Occupancy Evaluation

Although post-occupancy building evaluations have become popular, pre-occupancy or predesign evaluations are almost nonexistent. That is, facilities or parts of facilities are seldom modeled (symbolically or physically) and tested for performance before construction. Buildings with repetitive space or important critical and unique spaces could be tested and evaluated before construction.

Research Topic

1. Design, construct and test a pre-construction performance evaluation facility and methodology, including an interacting physical mock-up situation with a computer simulation modeling capability. Evaluate the functional performance qualities of typical components of building types and unique critical spaces, and correlate results with post-occupancy evaluations of built projects.

I C 3 Research Issue: Objective Measures of Spatial Organization in Architecture

Traditionally, attributes of the components or subsystems used to create architecture and attributes of the physical or behavioral performance produced by a particular architectural work have been specified with much greater objectivity and precision than the truly "architectural" attributes of building and other designed settings. Aside from a few nominal typologies (low-rise, high-rise, etc.) there are no objective taxonomies presently for classifying or comparing buildings and other settings according to their architectural qualities. Instead of focusing on the essence of architecture, most architectural researchers continue to work with the issues, concepts, and methods central to other disciplines - primarily engineering and the behavioral sciences. However, that which sets architecture apart from the other field concerned with the design or use of buildings and other settings is its primary concern with the arrangement or organization of space and with the relationships between the elements that bound or define space. Until spatial organization and spatial relationships can be specified, sampled, or measured with precision and objectivity, systematic analyses of cost or performance will not be generalizable from one building to another, and no genuinely "architectural" research will be possible.

Research Topics

1. Assessments of the applicability of the spatial analysis methods (networks, matrices, branching flows, stereology, contact fields, etc.) used in geography, industrial engineering, topology, and other fields to the central spatial issues current in architecture should be conducted.

2. Modeling of spatial relationships within and between buildings with regard to the performance of structural and mechanical systems under normal and abnormal loading conditions should be pursued. Problems include extraordinary live loads; effects of shape on seismic and wind

loadings; identification of stable refuge zones in emergencies; variable air flow and stagnation; patterns of flame spread and smoke build up; and flashover potential, et cetera.

3. Modeling of spatial relationships within and between buildings with regard to the conduct of activities by building occupants under normal and abnormal operating conditions should be pursued. Problems include visibility of critical information; required proximities and separations; route selection at choice points; conflicting and redundant circulation routes; light/dark adaptation; regulation of crowd flow during egress and ingress, et cetera.

I C 4 Research Issue: Environmental Patterns

Architects and engineers tend to rely on published references as sources of information for their planning and design activities. While many use documents such as Graphic Standards for size and detailing data, an increasing number have turned to sourcebooks such as Alexander's Pattern Language for behavioral information. In doing so, these environmental designers have demonstrated a sensitivity to the human requirements of building. Yet, there is evidence to suggest that many of the patterns offered are not empirically-based nor does the repertoire of patterns reflect contemporary environmental settings. There is a need to develop empirically-based patterns or zones which are comprised of bundles of environmental attributes.

Research Topic

1. In addition to research which examines discrete environmental attributes and combinations of such attributes in relationship to peoples' actions and feelings, study is needed to define empirically-based patterns or environmental zones for use by architects and engineers in their design

activities. For example, the need for such research is acute in office plannning, where new technology is changing both the physical requirements and the modes of work. By examining a wide range of offices which use new approaches to information storage and retrieval, wordprocessing, et cetera, a number of patterns or zones reflecting bundles of environmental attributes could be identified. Hypothesized behavioral and attitudinal responses of workers to these patterns would be posited and then empirically tested. Based on the results, modifications to the patterns would be made and published. The value of such patterns lies in their potential usefulness to office designers as a reference. Similar research could be conducted in any number of important environmental settings.

I D PROCESS OF DESIGN AND CONSTRUCTION: COMPUTING

Introduction

The process of design and construction has become increasingly complex. Buildings with simple objectives and single clients are rare; multiple objectives and institutional clients are the norm. Obsolescence follows an increasing rate of socio-technological change. Traditional methods and materials fall to better technology, organization, and resource conservation.

The use of the computer in architectural processes creates potentially revolutionary effects in both design and construction. More efficient information storage and retrieval, design process, performance predictability, and systems control are all within current computer technology. The knowledge building required to realize this potential of computer tools lies mostly in the development of conceptual frameworks, and the development and testing of software techniques. Particularly important are the development of representations of building systems, methods of evaluation, and user interface controls.

1. **Development of Computer Representation of a Building Design Project**
2. **Building Composition Combinatorics and Evaluation Methods**
3. **Expert Knowledge Systems for Building Diagnosis**
4. **Computer Prediction of Building Performance**
5. **Building Subsystem Design**
6. **Building Systems Control**
7. **Application of Electronic Memory to Design Process and Other Architectural Concerns**

I D 1 Research Issue: Development of Computer Representation of a Building Design Project

Computer aided architectural design has, for the most part, been unrealized. A fundamental reason for this is the complexity of most building projects and the inability to develop models of these projects in computers. This issue involves the development of a computer representation of a building design project, including its geometry and component attributes, structures to support design development, and evaluation. Analyses and drawings could be produced from building models. Such an integrated representation would support: (1) efficient analysis, by automating the generation of input; (2) further automation of detailing and design support activities; (3) automatic checking of the design for integrity and consistency; and (4) better coordination among parallel design tasks by the sharing of information. Global goals are both increased productivity of designers and designs, and better prediction of performance of the designed artifact.

Research Topics

1. Development of data base systems facilities for spatial and nonspatial data to allow real-time interaction, dynamic schema definition and other features unique to design needs.

2. Development of methods for structuring the data base schema so as to allow various combinations of technologies, concurrent design development and automated checking.

3. Development of methods for managing the logical integrity of a design model, for encoding the logical relations, and to control when to check them.

4. Development of methods to allow complete automation of drawing production from such a model, including dimensioning, line weights,

annotation, et cetera.

5. Development of an interrogation language that would provide a high level syntax for writing integrity checks for such a design model; for instance, for encoding building code checks.

6. Development of high level language for defining the layout or detailing of such a building model.

7. The study of the integration of a computer building model with various existing building system analysis techniques.

8. The study of the difficulties and potential caused by the changes in architectural design methodology which could occur through the use of computer aided design.

I D 2 Research Issue: Building Composition Combinatorics and Evaluation Methods

Most buildings are composed of discrete elements or elements that can be defined discretely. These elements can be combined in finite ways. Only a subset of this combinational set represents the significant alternatives that are distinct in terms of decision choices and respond to general criteria. Recent work has shown that algorithms can be developed in many design areas to mathematically enumerate the set of significant alternatives for a subsystem design. These can be encoded and stored or the algorithm can be used to enumerate alternatives for a particular contextual condition. Enumeration is a necessary precursor to optimization. This would lead to decision methods that allow proof of the qualities of the relative performance of an alternative set over the feasible set.

Research Topics

1. Development of formalisms for encoding a subsystem design that makes it amenable to enumeration; for example: (a) building plan layout, (b) multiple uses on a site, (c) structural framing, and (d) mechanical systems.

2. Development of cross-reference schemes for accessing enumerated alternatives; essentially consisting of defining the indexing terms that respond efficiently to a set of accessing criteria.

3. Development of enumeration methods that efficiently eliminate combinations identified by the user defined constraints.

I D 3 Research Issue: Expert Knowledge Systems for Building Diagnosis

Many types of building and building system evaluation have eluded conventional quantitative techniques of analysis. Artificial intelligence research in computer science has responded to this general problem by modeling the qualitative diagnosis of human experts, using pattern recognition and theorem proving techniques, among others. These methods of automated diagnosis could be applied to buildings and other forms of design. This technology would be a response to both limitations of knowledge and knowledge transfer. Also, it is an important means of incorporating criteria that are used by dispersed classes of decision-makers.

Research Topics

1. Development of formal computer languages for specifying building design conditions (as shown in architectural drawings and computerized building models) that are of concern in building diagnosis.

2. Develop and test language-system capabilities in areas of high relevance; for example:
    - a) Site Planning analysis of drainage, acoustics, sightlines, views;
    - b) Ergonomic Review evaluation of safety, legibility, emergency egress conditions;
    - c) Architectural Detailing earthquake hazards, other architectural problem areas.

I D 4 Research Issue: Computer Prediction of Building Performance

The accurate prediction of the performance of buildings prior to their construction has been recognized as a necessary part in the design of buildings that are responsive to the environment in which they are located. The development of high performance, low cost computer and simulation software should make these predictions a reality for most building projects. The fundamental research issue is how this is to be accomplished.

Research Topic

1. Review and evaluation of building performance evaluation techniques, followed by the development and testing of techniques for low cost computers. Research should also address the potential integration of this computing technology into the building design process.

I D 5 Research Issue: Building Subsystem Design

Most building subsystems must respond to multiple functions; often these drive the design in divergent directions. Criteria for good design are not explicit. Methods that allow for the efficient generation and evaluation of alternative subsystems by multiple criterion are needed. The development of this computing method would have an impact on the work of building architects, engineers, and construction managers.

Research Topics

1. Development of indices that logically combine the multiple performances of various subsystems, so that they may be more readily evaluated.

2. Development of qualitative assessment techniques, such as for maintenance efficiency, self-cleaning of buildings, et cetera.

3. Development of subsystem evaluation tools; for example, in (a) mechanical equipment selection, for heating and cooling performance under varying loads, maintenance considerations, and control design; (b) exterior building shell design, for detailing thermal performance, dew point and moisture resistance, natural lighting, self-cleaning, maintenance, et cetera; and, (c) interior partitions, for acoustical and lighting control and dispersion, flexibility, cost, et cetera.

I D 6 Research Issue: Building Systems Control

Computers in building control. Microprocessors are increasingly being used to control elevator/vertical transportation systems and HVAC/mechanical equipment systems. To what other uses may small, inexpensive microcomputers or minicomputers be put, as a permanent installation in the building itself? And, what impact will dramatically improved and flexible control have on the architecture of the building, -- the form and function of the whole building and its component subsystems.

Research Topic

1. We need to survey the existing control functions of various building types, as well as existing and anticipated microprocessing capabilities. Potential applications and the impacts of such applications should be indentified, developed, and tested.

ID 7 Research Issue: Application of Electronic Memory to Design Process and Other Architectural Concerns

The technology of electronically storing information, for access by various digital and analog devices, has made a dramatic research breakthrough in the past decade. All indications are that even more dramatic improvements are on the way. This will make very large storage devices available at a modest price. How to use that capability for improving the design of buildings and communities is a "question that awaits an answer," and a phenomenon (man/machine interaction) we need to understand.

Research Topic

1. Storage and retrieval of Architectural Design "handbook" data (such as the AISC steel handbook or the ASHRAE handbooks). An analysis of the fundamental structure of the data now stored in handbooks, and intended to be manually searched by the user, to formulate conceptual models for storing the same data in random access electronic memory. The conversion of manual methods of design calculations to ones which are computer-based will be greatly accelerated by conceptual models for storing and retrieving the data bases needed in calculations.

2. The analysis of electronic monitoring and control systems for the HVAC systems in buildings augmented by very large memory; an evaluation of

the performance potential for electronic memory systems if very large amounts of data were associated with the methods of monitoring and control. The response to user requirements on an individual basis could become a part of the comfort package when sufficient memory existed to store each person's preference, space conditions, and HVAC control parameters.

3. Memory storage of building occupancy. Conceptual design of monitoring devices at points of building ingress and egress, that commit to memory the physical dimensions of each person entering space and remove the same from memory on egress. Building load calculations for HVAC could be programmed from this data; when emergency occurred the information in memory would provide security data to police and fire officials and where persons may still be located.

4. Climatic data storage. An analysis of climatic data that might be stored if the size of the data bases was no constraint. For example, in very tall buildings climatic data might be stored for each face of the building at each floor in order to program HVAC system. Close fit between prediction of weather conditions and historical climate data will allow the control systems for HVAC to anticipate micro-climate changes in each of the sectors of a large building.

5. Balance of daylight and artificial light in classrooms. Analysis of occupancy patterns in classrooms (in various types of schools), related to the potential contribution of natural light, would allow individual student light conditions to be monitored and controlled. This would create the combined advantage of energy conservation with more flexible response to user needs.

II. BUILDING HABITABILITY

A. Environments

B. Users

II A BUILDING HABITABILITY: ENVIRONMENTS

Introduction

Design and construction at the building, urban, and regional scale produces relationships between the physical environment and people that are clearly powerful, but poorly understood. How does design -- the essential spatial organization that the architect conceives and the environmental systems that he chooses to control the thermal, lighting, and acoustical environment - support or detract from the endeavors of persons and groups: in time, comfort, productivity, learning socialization, and the like.

In developing our theory and knowledge base, research focuses on building performance and human interaction. In designing a building, the architect and engineer predict its performance: in terms of light levels and temperatures, and in terms of comfort, efficiency, and pleasure. Useful definitions of comfort remain elusive, -- we can see that comfort is one point on a continuum of human response, both mental and physical, that ranges from intensive pleasure, thorough enjoyment, comfort, discomfort, mild ill health, severe ill health, to death. One might argue that furthering our understanding of the relationships between ourselves and the built environment represents the basic research of architecture, -- not in itself problem solving, but in providing the knowledge that forms the basis for decisions made in professional practice. To the extent that pleasure, comfort, efficiency, productivity, and good health are objectives of building owners, operators, and users, the impact of the built environment on these factors must be known more precisely.

While we may say that these issues represent basic architectural research, clearly they are not basic science in the traditional sense. To improve our knowledge we must use the basic knowledge of physics, biology, mathematics and the social sciences; the development of methods to do this forms the general methodological issue of research in these areas. We must develop integrative methods to deal with

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integrative problems, -- when human purposes enter the picture the whole truth cannot be found solely within the laws of physics.

The issues and topics described in this section represent only a selection of items within two broad areas: general Environments and Environmental Systems. Items with a more direct health component are included in Section III, Human Security and Safety.

BUILDING HABITABILITY: ENVIRONMENTS

1. **Circulation and Access in Buildings**

2. **Habitability of Exterior Environments**

3. **Development of Test Methodologies**

4. **The Mundane Environment**

BUILDING HABITABILITY: ENVIRONMENTAL SYSTEMS

5. **Environmental Quality and Worker Productivity**

6. **Failure of the Interior Thermal Environment**

7. **Interaction of Thermal and Lighting Environments**

8. **Design Assumptions and Actual Performance of Building Lighting Systems**

9. **Impact of Occupant Manipulation on the Performance of Mechanical Systems in Buildings**

10. Effectiveness of Low Intensity Radiant Heat Sources on Human Comfort

11. Cost and Small Scale Environments

12. Earth Covered Environments

II A 1 Research Issue: Circulation and Access in Buildings

Current methodologies in the research and design of circulation systems tend to focus on functional aspects, with efficiency measured in length of route and quantity of space. However, people often have to learn to find their way in complex and unfamiliar buildings. Some experience great difficulty while others seem to master the use of unfamiliar buildings quickly and efficiently. The problem may be particularly acute for the visually or mentally handicapped. The implications of learning one's way around an unfamiliar building range from frustration and anxiety in not being able to locate a destination, to one of life safety in terms of exiting a building under emergency conditions, such as fire or earthquake.

Research Topic

1. The relationship between the process of acquiring and using building information and effectiveness in routine and emergency situations should be approached via research with controlled observation and experiments with human subjects in various building and mock-up situations, -- with particular reference to signals and clues that are used. Visually handicapped persons would be included because they are an important user group, and may provide important insights into the clues that all people use. This knowledge would be useful for the design and redesign of buildings, information and signal systems, emergency systems, circulation design and the like. (Work in this area is forthcoming from

the NFPA 101 Life Safety Committee.)

II A 2 Research Issue: Habitability of Exterior Environments

The interactions among building site factors, microclimate, and human activity affect the success of site design in terms of comfort, convenience, and safety. Unsuccessful designs may have serious economic consequences through lack of use; efforts to avoid adverse climatic effects by enclosing large commercial areas can waste energy and resources. Rationalized design of outdoor environments is in its infancy; better information is required to improve the quality and range of design applications.

Research Topics

1. Human comfort requirements under a wide range of outdoor climatic conditions. Thermal physiological research has stressed the effects of outdoor conditions on the comfort of conventionally clothed civilians. Research should address thermal comfort of various populations, -- in the laboratory, by survey outdoors, or by refinement of mathematical models of human thermal physiology. Transient conditions should be stressed. Results would have wide application in architecture, landscape architecture, and urban design; they would be an important step in developing a rational procedure for siting and designing buildings for a given climate.

2. Outdoor comfort criteria should be developed. How uncomfortable must outdoor environments be before users seek alternatives? Owners and users should be surveyed; responses should be compared to responses from physiological models. This information could lead to the development of climatic performance specifications for exterior and semi-enclosed environments.

3. Microclimatic investigation of building configurations and of design measures that improve outdoor space habitability. Studies would be performed using physical models in laboratories (wind tunnel, solar simulator), micrometeorological field studies, and a few numerical simulator techniques. Benefits would be to prescriptive design standards, and categorizing designs effective for various climates.

II A 3 Research Issue: Development of Test Methodologies for Theories on Fundamental Relations Between the Physical Environment and Human Behavior

Despite over a decade of research on human factors at the building, urban, and regional scales, little is known about fundamental relations between the physical environment and human response systems, for example, how design and spatial organization affect learning, socialization, productivity, physiological comfort and other human behaviors.

Research Topics

1. Comparative assessment of major and urban theories. Competing theories linking the organization of physical space to human response systems have been promulgated in the literature. In some cases, studies have been generated to extend one or another theory. In other cases, the theories have served as heuristics for specific experiments or field studies. In very few cases, however, have the theories been subjected to tests capable of falsification, nor have critical tests been developed to empirically compare theories. Approaches to this fundamental issue center on the development of critical tests of strong inferences in varied settings. Examples would include the test of cognitive environmental theory by assessing the degree to which cognitive representations of different building layouts actually affect movement, orientation, and

memory for aspects of those buildings, or the test of symbolic interactionist theory of environments by assessing the ways in which members of different socio-cultural groups use buildings and urban environments differently. The impact would be to advance the theoretical state of the field.

2. Fundamental processes of environment-behavior relatedness. A myriad of studies have been published on this or that user group in this or that building and urban setting. Often the fundamental relations between the organization of physical space and human response systems have been overlooked or ignored. Fundamental relations include ways in which the organization and character of spatial environments affect child development, the processes of aging, the prevention of disease, the reduction of stress, productivity at the workplace, and hospital recovery rates and outcomes, among other critical human conditions. The critical methodological issue is to focus on the right research question addressing a comparative assessment of fundamental aspects of the human organism and the social system, not peripheral questions capable of easy answer. Methods to study these issues include the articulation of critical outcome variables (developmental gain, recovery rate, stress reduction, etc.) and factorial designs to identify critical environmental variables (air exchange rates, temperature ranges, glare, density of occupancy, provision of social space, etc.). Methods must address cross-group comparisons (e.g., cross-cultural, urban-suburban-rural, cross-ethnicity, cross-age groups). The focus of this topic of research is the development and testing of explanations accounting for the effects of building and urban variables thought to be critical to outcomes.

II A 4 **Research Issue: Mundane Environment**

Analysis of the "mundane environment" in terms of environmental research directed towards understanding the everyday environments in relation to various technological developments.

Research Topics

1. Analysis of exposure to noise levels outside the working day and its relationship to long-term hearing loss. To what extent do individuals take "avoiding action"? Does continued exposure lead to de facto tolerance of differing standards of exposure? This is a case of building on work done by OSHA, NIOSH, FAA, EPA, et cetera.

2. Relationships between use of space in the home and patterns of energy utilization, bearing in mind technological advances in domestic appliances. Relationships among building modifications, behavioral modifications, and energy consumption patterns.

II A 5 Research Issue: Environmental Quality and Worker Productivity

There is continual pressure to design and redesign interior environments in ways that decrease building cost. Visual and acoustical privacy, occupant views, user control of environmental conditions (lighting, temperature, humidity, ventilation, etc.), and selection and arrangement of furnishings have been reduced or eliminated without knowledge of the impacts of these changes on performance. However, studies indicate that increased expenditures for office buildings can be justified economically by small increases in worker performance. While recent experiments indicate that very large increases in lighting levels result in very small increases in peformance, other impacts of these changes must also be evaluated, -- including attendance, health, and satisfaction of occupants. Though the correlations between the environmental variables and worker performance are difficult to establish, this represents a fundamental area of research that is of great importance.

Research Topic

1. Productivity analysis of varying indoor environmental conditions. Analysis of worker health, attendance, and production records can be compared with building environmental qualities which fall within the designer's scope of decision-making. Assumptions of building owners and employers can be compared with actual performance. Case studies, interviews, analysis of work load and production changes over time, and monitoring and characterization of critical environmental variables can result in a significantly improved design basis for a variety of contemporary work environments.

II A 6 Research Issue: The Failure of the Interior Thermal Environment

The poor quality of the thermal environment in our buildings is so common as to be accepted by the users as inevitable. The national losses in productivity and physical comfort through over-heated, over-cooled, drafty and stuffy interiors are vast. Although the whole subject has received some research attention, practice is largely based on long outdated and untested rules of thumb.

Research Topics

1. Detailed case studies of specific buildings whose performance is clearly established as detrimental to its occupants. The case study focus must be on the institutional, economic and professional reasons for environmental system failure.

II A 7 Research Issue: Interaction of Thermal and Lighting Environments

Requirements for thermal and visual comfort in indoor environments have a wider range of thermal and lighting variation than has been studied in the past. The interaction of thermal and lighting levels and quality in affecting comfort is largely unknown. In addition, the psychological function of windows on visual comfort and thermal comfort is unexplored. Answers to these issues could have substantial effects on saving energy in buildings through modification of environmental management and design of fenestration.

Research Topics

1. The influence of temperature and light level on comfort and satisfaction should be investigated in a realistic architectural setting, for various populations around the United States. The work should be carried out for day-lit and artificially-lit interiors, and the functions of windows for view should be controlled. Tests should be carried out in realistic test chambers with variable fenestration, and in real workplace settings with and without windows and skylights. The results are very important for the goal of integrating thermal and lighting efficiency in buildings.

2. The importance of glare as a specific aspect of visual comfort needs to be determined as well. This issue is very important in determining the measures to be used for lighting in studies like the ones above; and it also has large implications for spatial organization within buildings and the design of fenestration. This work would be performed in laboratory settings, in the effort to determine the relative influences of glare on visual comfort and window size on the psychological need for a view of the outdoors. The results could have significant implications on the way the building exterior skin is handled in the design process.

II A 8 Research Issue: Design Assumptions and Actual Performance of Building Lighting Systems

Fluorescent lighting has generally replaced incandescent sources under the assumption that its use would conserve energy and increase economic benefits. In actual use, fluorescent lights are generally installed further from the work or task area, are specified at higher peformance levels, are less flexible and less subject to user or building operator modification and control. Task and ambient lighting approaches are compared with little data base from our past twenty-five years of experience. Measures of actual versus specified lighting levels are infrequently made. We need far better data on lighting performance and use characteristics, and on the relationship of these data to design assumptions.

Research Topics

1. Case studies and comparative analysis of various lighting systems in actual use. Interviews with building designers, users, owners, operators, and employers, along with data on actual lighting conditions and design specifications, can be modeled and analyzed to enhance our knowledge of the actual impact of lighting design decisions on cost, performance, and occupant behavior (productivity, satisfaction, preferences).

2. User preferences in lighting system design. Few individuals express preference for overhead, uniform fluorescent lighting. Some occupations may require such lighting while others may suffer from its use. Interviews and case studies of real installations can result in enhanced understanding by designers of appropriate applications of various lighting alternatives, and serve as the basis for later systematic simulation and field studies.

II A 9 Research Issue: Impact of Occupant Manipulation on the Performance of Mechanical Systems in Buildings

Traditionally, mechanical subsystems within buildings are constructed solely in engineering or hardware terms, with the behavior of the building's occupants generally considered to be outside the system. However, in many cases it has become clear that the ultimate performance of the system is a joint function of the performance of the equipment and the manner in which that equipment and other parts of the building are used. For example, many passive solar installations will fall short of their performance goals if the occupants leave certain doors open, put rugs on the wrong floors, fail to operate louvres properly, or put plants on the light shelves. A more critical example occurs in the compartmentalization of buildings where doors that should remain closed to control the spread of fire and smoke are often opened by people trying to confirm the existence or extent of a fire or by people trying to escape from a smoke-free refuge area because they have no idea if anyone knows that they still need to be rescued or how long a two-hour door will protect them. The issue here is not simply better hardware but rather to redefine the problem so that the equipment and the occupants can act together as part of a single system. This is essentially an interdisciplinary research issue, requiring the contributions of architects, engineers, and behavioral scientists.

Research Topics

1. Determine the extent to which occupant manipulation actually affects the performance of fire protection, energy conservation, and building security systems, using real-time observational data on occupant behavior and instrumented data on system performance using the designer's prediction of building performance as a baseline.

2. Conduct laboratory and field experiments or simulations to determine

the primary hardware and behavioral parameters of mechanical system performance and the best means for optimizing that performance without jeopardizing the occupants' need for some control over their environment.

II A 10 Research Issue: Effectiveness of Low-Intensity Radiant Heat Sources on Human Comfort

Passive solar building technology has introduced large area, low temperature heat sources (e.g. warm masonry walls) into occupied spaces. It is expected that this will result in comfort conditions without the need to warm the entire air volume of the building. However, low temperature radiant effects on comfort are inadequately understood in relation to present trends in the design of these types of buildings.

Research Topics

1. Human comfort studies of the effects of large area, low intensity radiant heat sources in combination with reduced ambient air temperature, related to contemporary building design.

2. Energy consumption and cost comparisons between conventional warm air systems and low temperature radiant systems.

3. Parametric studies of human comfort, to determine minimum surface temperature and area required to permit reductions in conditioned air temperature.

II A 11 Research Issue: Cost and Small Scale Environments

The twin impacts of energy conservation and continually escalating building costs are combining to produce residential and other constructions characterized by fewer windows, lower ceiling heights, and smaller rooms. There is a need to investigate consequences which may adversely effect behavior and satisfaction with the home and other environments. Research is needed to anticipate such problems and create design solutions.

Research Topic

1. Investigation of experience in small scale environments: ships, space craft, military installations, and correctional facilities. Study of these extremes may give important clues as to effects that may be experienced in everyday life, including: the design, construction, and evaluation of small scale living environments using real subjects under controlled conditions, and the evaluation of experience in constructed environments under moderately extreme conditions, such as college dormitories and military barracks.

II A 12 Research Issue: Earth Covered Environments

Earth covered and underground buildings are known to be capable of reducing large annual air temperature variations. However, the practical use of such buildings depends on the ability to predict thermal response as a function of climatic conditions and soil characteristics. Until confidence in the prediction methods can be improved, the energy saving potential of these buildings may not be realized.

Research Topic

1. Prediction of changes in soil characteristics in relation to earth covered architecture as a function of geographic region and weather conditions. Evaluation of the performance of full-scale models will be compared to the results from various simulation techniques which incorporate the subject characteristics.

II B BUILDING HABITABILITY: USERS

Introduction: Understanding How to Make Buildings That Provide for the Needs and Abilities of the People Who Use Them

This group of agenda items is concerned with the development of a theory base that can be utilized for making building design decisions that deal with how well buildings and parts of buildings match the physical, mental and emotional needs and abilities of the people who use them. This part of the agenda must include studies that will help us know how to examine people's abilities and perceptions and how to measure the environment in terms of human responses.

At one level the agenda is concerned with how to design a door handle that can be opened by essentially everyone (not as easy as it seems); on a larger scale the agenda would encompass the thorny problems of trying to understand the relationship between human behavior and buildings -- to what extent and in what way can buildings be held responsible for human actions? At yet another scale, we are concerned with the notion of appropriate building settings for certain human activities. Can environments be designed that can improve the quality of life of factory workers, elderly people, and hospital patients, for example, and increase productivity? In fact, at all levels the agenda should include the development of knowledge on the environmental "fit" between people and buildings in terms of safety, comfort, satisfaction and function.

Our comprehension of the supports that buildings must provide for the physical and intellectual abilities of people is far less developed than our knowledge of building construction technology. Society hears quickly of physical building failures -- roofs and walkway collapses, earthquake damage, et cetera, but it is the failure to match human needs that is more pervasive, albeit less dramatic. We know that our buildings, which in many ways do not fit adequately the capabilities of children, elderly people and the handicapped; often in fact, do not seem to work well for the rest of the population. Designers are frequently criticized because buildings don't appear to be functional.

The truth is that the theoretical underpinnings of building design for the human users are meager. In part, this may be because it is usually easier to study things than people; and partly because it is comparatively recent that building life cycle studies have demonstrated the importance of the costs of effective human utilization in the equation of expenses and benefits. Whatever the reasons may be, the human/machine interface seems to have received greater attention than the interaction between people and buildings. Even within buildings this seems to hold true. The theoretical knowledge which can be used to predict, for example, how people use elevators and escalators has been established; the theoretical knowledge which can be used to predict how the same people will respond to a fire when these mechanical devices are off-limits is inadequate.

The agenda that follows is sequenced in terms of scale; it starts with a recognition that the tools for measuring human responses (other than physiological responses) are inadequate, and therefore, we know little about how to calibrate environments for their many purposes (issue 1). A special subset of this understanding is the question of how people comprehend environmental complexity (issue 2). If we had better tools for measuring this type of environmental fit, then the design professions could do a better job of generating buildings that are easier to use because they are easier to understand.

Another special circumstance that has become particularly perplexing and is addressed in the agenda is that buildings last for a long time, while social and technical change proceeds rapidly (issues 3 and 4). We sometimes build buildings that may be obsolete even before they are occupied; and most buildings cannot effectively perform their intended functions for long time periods. Certainly part of the problem is that the design professions have not studied adequately the trends of social and technological change that affect buildings.

In some cases we have made these studies. For example, long life, low energy, and loose fit may be used as the basis for hospital design. The principle of "loose fit" here refers to the idea that medical technology undergoes more or less complete change in as little as five years, and that growth and change is endemic to the diagnostic and treatment services. The loose fit provides the conceptual basis for change and expansion to take place without too much trauma for the rest of the hospital.

The next portion of the agenda focuses on the scale of personal interaction with the various parts of buildings (issues 5, 6, 7 and 8). Accidental death is a major cause of mortality for all people, and particularly for children and the elderly; and the majority of these results from a failure of elements of the building environment to protect people. For example, the Consumer Product Safety Commission has rated stairs as the most dangerous product. After thousands of years of stairs, we still do not know how to design safe stairs. Similarly, we do not yet know how to design bathrooms, for example, that can be used safely and adequately by all segments of the population. We have learned (to our surprise) that the greatest part of most buildings are still designed for the convenience of young, able-bodied adults -- who constitute less than half of our population -- and are unusable or difficult for the remaining majority to use. This discovery is likely to have profound effects on our future buildings. However, at this time it leaves us caught short. We need to examine and reexamine almost everything to do with buildings before we can design for the whole population. This, in itself, is an agenda that will take many years to work through.

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Issues include:

1. **Standardized Methods and Instruments for Measuring Built Environments and People's Responses to These Environments**

2. **Human Comprehension of Complex Building Layouts**

3. **Settings to Accommodate Emerging Forms of Social and Technological Organization**

4. **Accommodating Long Term Social and Technical Change**

5. **Human Factors and Building Elements**

6. **Critical Aspects of Human Behavior and Well-Being for Special Populations**

7. **Optimizing the Match Between Demands on the Built Environment and the Competence Level (Ability) of the Individual**

8. **Design of Working Environments**

II B I Research Issue: Standardized Methods and Instruments for Measuring Built Environments and People's Responses to These Environments

There is general agreement that methods for measuring attributes of buildings and larger scale environments (e.g. neighborhoods) vary greatly in scope and sophistication. Similarly, there are numerous instruments designed to measure people's responses to physical environments, but many have been hastily adopted from other social science uses, where environmental factors have either been screened out, or used without having been systematically pretested to identify systematic bias. There is also some question as to whether physical system measurements are as accurate and precise as social system measurements. In order to increase the reliability and efficiency of evaluating built environments and people's responses to them, architects, engineers and behavioral scientists need better calibrated and more standardized tools of measurement.

Research Topic

1. Development of prototypical instruments for measuring (a) attributes of different types of built environments and (b) behavioral and attitudinal responses to these environments and their attributes. The types of environments to be considered provisionally would be categorized under office settings, residential settings, industrial settings, recreational settings and institutional settings. The methodology would consist of four parts. First, a systematic review of empirically-based research covering each setting would be made to identify sets of measures used in recent years. Second, the measures would be evaluated using a "round-robin" sequential measurement process in which a reference unoccupied environment is evaluated by i researchers using j techniques. Then the environment is occupied by a sample of users pursuing a well-defined task. The result of the technique will determine which of those are deemed reliable, valid and salient. The measurement group would be practitioners and researchers from architecture, engineering, environmental planning and the behavioral sciences. Finally, a compendium of standardized measures indicating their intent, reliability, validity and relative ease of use would be prepared.

II B 2 Research Issue: Human Comprehension of Complex Building Layouts

Hospitals, airports and transit facilities, large office buildings and other large complexes often are difficult for people to use because of their size and layout. They challenge the comprehension of the average intelligent adult and confuse those who have weaker cognitive comprehension or who have poor eyesight. The problem may, at least, cause inconvenience and, at worst, be disastrous in the event of emergencies such as fire. At this time we know relatively little about these human spatial comprehension skills and, therefore, we have difficulty in designing buildings or signage systems to avoid confusing environments.

Research Topic

1. Emergency egress for the visually impaired. The ability of persons to find their way through an environment during an emergency, such as a fire or other emergency, is largely dependent on their cognition of that environment. This cognition is affected by the person's conceptualization of space and the available cues for route-finding given by signage and other mediums for communication. In many emergencies many persons will lose perception of one or more senses; for example, during many fires the smoke will obscure visibility to the point where persons become virtually blind. Our understanding of how persons conceptualize space can readily be improved by studying those persons who have some form of sensory deprivation, particularly the blind and deaf. Experiments can be carried out using persons with sensory deprivation and those without such deprivations, to test the effect of different perceptual cues on route finding. The immediate benefit of such work could be the development of aids for those with sensory deprivations.

II B 3 Research Issue: Settings to Accommodate Emerging Forms of Social and Organization

During the past century several major changes in patterns of social organization have emerged in the Western World. Among these are: dissolution of the three-generation household, coupled with the emergence of adolescence as a separate stage in the life cycle, and the "normalization" of non-mainstream adult populations in the form of group homes and scattered-site public housing. In addition, numerous technological changes, such as those occurring in the telecommunications and public transportation areas, continue to introduce new social opportunities and obligations. With rare exceptions, the implications of such sweeping societal changes for the provision of new settings and new spatial arrangements have not been anticipated by the traditional arts and sciences. As a result, the elderly, the poor, the disabled, and even the adolescent continue to be ill-served by the types of environments provided in the marketplace. Given the capabilities in the past, there is little cause for optimism that similar needs can be met in the forseeable future without substantial new research in the social and design sciences.

Research Topics

1. Compile architectural data on the typical spatial environments of teenagers over the past several decads. Using archival records settings range from soda fountains and drive-ins in the '40s and '50s; through airports, cruise circuits, and shopping centers; to the electronic game parlors of the '80s should be considered. Factor analytic and comparable sorting methods can be used to identify attributes common to these settings. If these attributes are then treated as basic environmental requirements for this group, then it becomes possible to evaluate contemporary settings provided for teenagers against these criteria. It also becomes possible to propose, build, and evaluate alternative settings that could meet these needs more effectively. One starting point for such research would be the experience and research potential of planned communities.

2. Using the same approach described above, develop data bases for anticipating the environmental needs of future generations. For example, time budgeting studies of today's pre-school children and middle-aged adults may provide valuable insights on the changing spatial needs of the next generations of adolescents and elderly, respectively.

3. Reexamine the manner in which emerging social groups have been

settled and sheltered in the past, using historical records. A useful starting point might be comparisons between those groups whose environmental needs have been well-served (childless couples, etc.) and those whose needs have not been well-served (adolescents, etc.).

II B 4 Research Issue: Accommodating Long Term Social and Technical Change

Changes in the work-place: the advent of microcomputers, wordprocessing, et cetera, presage a significant change in work habits, and possible the home as a work-place, linked elecronically with a company center.

Research Topics

1. Broad investigation into the full environmental implications of a fundamental change in work habits: who it will affect, social implications, economics, the work setting, the home as a work-place, et cetera. Investigate existing models; develop alternative scenarios describing ways in which technology might affect the form and organization of buildings and communities in the future; emphasis on widest range of possible events. Exploration of implications of possible future events on the design of today's buildings, for example, what kinds of change might have to be accommodated? The resultant designs would better adapt to social and technical change, thus increasing long term utility and satisfaction.

2. Advances in communication technology. Computer and video systems are redefining how people relate to each other and the work space. How will these changes alter requirements for residences, offices, and commercial buildings?

II B 5 Research Issue: Human Factors and Building Elements

Bathroom fittings, stairs, switches, security systems, thermostats, knobs, door and window hardware, et cetera are poorly designed for the needs of children, the elderly and handicapped (and often for all people). This equipment does not match the physical abilities of the users, and needs have not been examined. We have better knowledge of the ergonomic needs of machinery and automobiles than of buildings.

Research Topics

1. Bathroom fittings. Measure the abilities of a representative group of people to use bathroom fittings. Record the specific disabilities and abilities displayed by the subjects. Redesign or modify the equipment. Field test. The results may indicate that existing equipment can be improved or that special additional equipment must be provided to allow for changing stages in the life cycle, physical abilities, et cetera.

2. Adaptive aids. In recent years there has been a great advance in providing features within the built environment for the benefit of disabled persons; at the same time there have been great strides in the development of aids to improve the abilities of individual disabled persons. It may be that building features mandated by laws (either actual or proposed) may be unnecessary as they assume a certain level of disability which with the advent of special devices may no longer exist.

3. Slippery floors. We have developed an increasingly wide range of synthetic flooring materials and finishes designed to reduce maintenance while remaining durable and attractive. Slip-type falls have become quite prevalent, particularly for the young and the old. Work on calibrating floor waxes for slip resistance has been carried out, but very little on the general range of materials is available to the architect. The development of a portable test machine, rather than a laboratory model, makes it possible to evaluate materials in use in a practical manner and

to develop better criteria. Use the Brungruber/NBS slip resistance tester to establish usable parameters for floor surface materials. The research would have to be done is several phases: (1) measuring the functional abilities of the population, (2) assessing the affect of various devices on the abilities of individuals, (3) forecasting the types of devices likely to be developed in the future, and (4) analyzing the cost-effectiveness of building features versus special devices. All these phases will, by themselves, produce useful knowledge.

II B 6 Research Issue: Critical Aspects of Human Behavior and Well-Being for Special Populations

The relations among building design, spatial organization, and some critical aspects of user behavior, performance and well-being need sustained and expanded research. A recent survey by the Environmental Design Research Assocation (EDRA) of research architects and professionals indicated that viable research questions still far outstrip research knowledge for the big three user groups: the elderly, children, and the handicapped. Other "underrepresented" and at-risk groups who have fewer opportunities to manipulate the environment and at the same time require greater environmental supports remain less studied, for example, people in institutions, prisoners, migrants, immigrants, et cetera.

Research Topics

1. Aging and the environment. The fastest growing segment of our population is the combined young-old and old-old out of the mainstream of working life. Health changes and environmental support have been reliably investigated. Life style changes, tradeoffs between community and privacy, social and emotional needs, and the impact of spatial organization have been far less studied. The relationships could be

studied via systematic, comparative, post-occupancy evaluations, time-series analyses involving environmental changes, and, in a few cases, controlled laboratory experiments. Impacts would extend to design concepts, design guides, private developer initiatives, standards, and codes.

2. The environment and human development. Considerable research has been and is being conducted on all aspects of child development, the effects of early experience, et cetera. Speculations abound on the effects of spatial organization on child development and early childhood education. Though the exact number of years varies between scholars, agreement still exists that the first five to seven or so years are the most crucial for later success and well-being. Few of the actual relations between the character and organization of the physical environment and fundamental processes of child development and learning have been empirically investigated. Methods would include standard child development laboratory and field methods, adapted to include explicit spatial environmental variables. Impacts would extend to design concepts, design guides, standards, and codes.

3. Handicapped and the environment. Barrier free environments and mainstreaming are now a part of national legislation. Their impacts extend primarily to the physically handicapped. Their standards and codes are in many cases based on experience, not research. Fundamental questions need to be asked that go beyond the impact of the removal of architectural barriers or the impacts on learning of mainstreaming the physically handicapped. In what ways does the physical environment impact on the mentally retarded? What aspects of the physical environment can have a therapeutic effect on children and adults with perceptual, auditory, learning, and emotional impairments? Are special theories needed to explain the relation of human response to environmental variables in the handicapped, or are the explanations covered as corollaries to extant major theories? Methods would include field studies, observational studies, interventions with handicapped persons, post-occupancy evaluations, and time-series quasi-experimental

designs. Impact would extend to design concepts, design guides, standards, and codes.

II B 7 Research Issue: Optimizing the Match Between Demands of the Built Environment and the Competence Level (Ability) of the Individual

Basic human needs remain fairly constant across the life span but the appropriate means of meeting these needs vary with the stage of the life cycle. The goal is to assist individuals in modifying the environment so that it is maximally supportive. The concept of matching demand with competence ranges from the micro level of the dwelling unit to the macro level of the community.

Research Topics

1. The relationship between environmental influences and personal growth.

   a. As a person grows into advanced old age or a younger person experiences a physical disability that is either temporary or permanent, the gap between the demand side of the environment and the competence side of the human response widens, and one's sphere of life-sustaining and life-enriching stimuli undergoes a continuous reduction. At the same time, an increasing proportion of energies are expended in satisfying only the barest life-sustaining needs with less and less time available for life-enhancing or life-enriching needs. Since this scenario describes how the physical environment can negatively impact on growth it is equally reasonable to posit hypotheses in terms of the physical environment impacting positively on personal growth.

   b. Household case studies regarding performance levels of activities of daily living including personal interviews, time-series data, behavioral observations and other approaches.

c. If certain types of environmental factors make it possible for a person to reduce by some portion the amount of time and energy it takes to perform activities of daily living, this would free up more time that could be spent in life-enriching activities.

2. Environment-behavior assessment tools. New or specially adapted methods need to be developed that can measure the subtle interaction effects of lifespan changes and environmental demands. Questionnaires, consumer surveys, the semantic differential, map drawing techniques and behavior setting observations, to name a few, are common research tools used in environmental and behavioral research that have limits to their utility among very young or very old people. New or specially adapted methods need to be developed, including direct observation and performance testing in real environments.

II B 8 Research Issue: Design of Working Environments

Working environments have traditionally been treated as means of production and their design have ultimately been governed by the pursuit of profits. Work environments have been judged according to their contribution to worker productivity, cost reduction, et cetera. In contrast to this approach there is a humanistic approach in which the work environment is judged according to its contribution to the full development and realization of the employees as human beings. It is becoming clear that the work environment may also generate unusual stress (air traffic controllers?) and may contribute to anti-social behavior, mental and physical health problems.

The control room of power plants, airports and industrial settings are examples of environments where the physical interface between man the worker and the machine (instrumentation) have been carefully considered. However, questions of boredom, lack of stimulation, and repetition are defeating the ergonomic effectiveness of the room.

Research Topic

1. Case study of a stressful environment. Perform case studies of environmental parameters of human failure in various work environments; develop and test modifications to typical work environments.

III. HUMAN SECURITY AND SAFETY

A. Health

B. Accident and Disaster

III A HUMAN SECURITY AND SAFETY: HEALTH

Introduction

There is need to examine much of the scientific evidence that underlies the sanitary and safety provisions of most modern buildings, codes, and commonly used standards. Most of the ventilation, lighting, plumbing fixtures, and room size requirements found in the current editions of the model building and housing codes are based on public health statistics and expert opinions gathered during the 19th century, long before the etiologies of the diseases believed to be at issue were fully understood in medical or epidemiological terms. Yet the set-back, window area, ceiling height, air change, and fixture unit requirements that were derived from this prescientific evidence continue to govern many aspects of building design in the 1980s. Given a complete reconceptualization of public health since World War II, together with the substantial costs associated with some of these provisions, a rigorous research effort would appear to be in order. Particularly, the impact of indoor air quality on the physical health and psychological well-being of building occupants should be studied, with specific emphasis on the relationships among modern ventilation technologies (recirculated conditioned air, inoperable windows, etc.), materials use, and modern building contents (xerox machines, cathode ray tubes, fluorescent lights, etc.).

The following issues are included in this section:

1. **Indoor Air Quality**

2. **Evaluation of the Health Effects of Building Materials**

3. **Impact of Automated Office Equipment on the Health and Safety of Office Workers**

4. **Radon-222 Pollution**

III A I Research Issue: Indoor Air Quality

Since the majority of the population spends more than 75 percent of their time within building structures, indoor air quality has major public health implications. Energy conservation measures of the past few years have reduced the air exchange rate of buildings substantially, thereby accentuating this problem. It is reported that for some pollutants (such as nitrogen oxides, carbon monoxide, carbon dioxide, polycyclic hydrocarbons, radon, and particulates) concentrations are greater indoors than outdoors. Moreover, for particulates, nitrogen oxides, and hydrocarbons, it is not uncommon to find interior concentrations above those allowed for the exterior environment by the Environmental Protection Administration.

What are the critical design and operational variables which determine indoor pollution levels? We need more information on materials, equipment, furnishings, maintenance requirements and building configuration with respect to contributions to indoor pollution levels. We need to understand which types of indoor pollution increase or decrease over time. We need a better understanding of the potential impacts of current building design and construction trends in relation to their impacts on indoor pollution. There is a need for assessment techniques to diagnose "problem buildings" and develop remedies which can be applied effectively.

Research Topics

1. To determine the extent of the interior air quality problem, there is a need to: (a) characterize indoor air quality in structures with different uses, types of heating and cooling systems, and different types of materials; (b) determine the effectiveness of different air filtration and ventilation systems upon air quality; (c) provide architectural input into the development of methodology and equipment to measure, with acceptable accuracy, low-level pollutant concentrations at a reasonable